PB-249 564

SINTER PLANT WINDBOX GAS RECIRCULATION SYSTEM DEMONSTRATION. PHASE I. ENGINEERING AND DESIGN

D. A. Pengidore

National Steel Corporation

Prepared for:

Industrial Environmental Research Laboratory

August 1975

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TECHNICAL REPORT DATA
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1. REPORT NO. EPA-600/2-75-014	2
3. RECIPIENT'S ACCESSION NO.	
4. TITLE AND SUBTITLE Sinter Plant Windbox Gas Recirculation System Demonstration--Phase 1. Engineering and Design	5. REPORT DATE August 1975 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) D. A. Pengidore	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS National Steel Corporation, Weirton Steel Division P.O. Box 431 Weirton, West Virginia 26062	10. PROGRAM ELEMENT NO. 1AB015; ROAP 21AQR-005 11. CONTRACT/GRANT NO. 68-02-1364
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Final; 6/73 - 3/75 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES	

16. ABSTRACT Windbox gas recirculation, as applied to a sinter plant, involves the return of a portion of the windbox exhaust gas to a hood above the sinter bed. The report develops the tradeoffs of recycle ratio versus oxygen content, moisture content, and temperature of the gases about the bed; total power consumption; and other important parameters. The basis for this parametric study, as well as for the full scale design developed therefrom, is operational and emissions data from two large modern sinter plants, taken as part of this effort. Recycle is projected to reduce hydrocarbon emissions to acceptable levels at reduced power consumption and capital cost relative to more conventional approaches. The advantages and disadvantages of various devices for final control of particulates are weighed: a gravel bed filter was the final choice. The report describes Phase 1 of a 2-phase project. Phase 2 will consist of an extensive test and evaluation of the full scale windbox gas recirculation system installed at the National Steel Corporation, Weirton Steel Division, sinter plant.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Sintering Furnaces	Stationary Sources	13A
Iron and Steel Industry	Windbox	11F
Dust	Gas Recirculation	
Hydrocarbons	Particulates	07C
Cost Effectiveness	Gravel Bed Filters	14A

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 140
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE $6.00

EPA Form 2220-1 (9-73)

EPA-600/2-75-014

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PHASE I. ENGINEERING AND DESIGN

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Contract No. 68-02-1364
ROAP No. 21AQR-005
Program Element No. 1AB015

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, D.C. 20460

August 1975

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Publication No. EPA-600/2-75-014

PHASE 1 - FINAL REPORT ABSTRACT

Windbox gas recirculation, as applied to a sinter plant, involves the return of a portion of the windbox exhaust gas to a hood above the sinter bed. The objective is to reduce the volume of waste gas to be cleaned and to conserve a part of the sensible heat in the windbox exhaust gas.

This report develops the tradeoffs of gas recycle ratio versus oxygen content, moisture content, and temperature of the gases above the bed; total power consumption; and other important parameters. The bases for this study, and the full scale design developed therefrom, are operating and emissions data taken from two large modern sinter plants. Recycling is projected to reduce hydrocarbon emissions to acceptable levels at reduced power consumption and capital cost relative to more conventional approaches. The advantages and disadvantages of various devices for final control of particulates were studied with the final choice for evaluation being a gravel bed filter.

This report describes Phase 1 of a two-phase project. Phase 2 will consist of extensive testing and evaluation of a full scale windbox gas recirculation system and a gravel bed final gas cleaning system installed at the National Steel Corporation, Weirton Steel Division, sinter plant.

This report was submitted, in fulfillment of contract number 68-02-1364, by the National Steel Corporation, Weirton Steel Division, under the partial sponsorship of the Environmental Protection Agency. Work was completed as of March, 1975.

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ACKNOWLEDGMENTS

The following personnel and organizations are recognized for their contribution and assistance in preparation of this report:

National Steel Corporation:

Great Lakes Division:

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Weirton Steel Division:

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Research and Development Division:

Mr. K. P. Hass

Arthur G. McKee & Company

Dravo Corporation

Environmental Protection Agency:

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SECTION I
CONCLUSIONS

A sinter plant windbox gas recirculation system was designed and installed on the Weirton Steel Division No. 2 Sinter Strand. The waste gas recirculation design point for this system was 39%.

No design or installation barriers to the successful use of waste gas recirculation have become apparent.

A twenty-four module gravel bed filter system, sized to handle approximately 50% of the waste gas, has been selected for full scale evaluation as a final particulate removal system prior to discharging the waste gas to the atmosphere.

SECTION II

RECOMMENDATIONS

It is recommended that the recirculation system be evaluated and that the test data be used in the selection of a final $\frac{1}{2}$ cleaning method.

The fine, noncombustible particulate matter remaining in the gas stream after recycling, can be removed by commercially available gravel bed filters, wet scrubbers, dry precipitators, wet precipitators, or bag house filters.

Information gathered during tests at the Weirton Steel Division indicates that a gravel bed filter will remove these particles at lower capital and operating costs and provide the reliability of operation required in modern sinter plants producing high basicity sinter. Therefore, it is further recommended that a gravel bed filter be tested on a full scale sinter plant windbox discharge, both with and without waste gas recycling.

SECTION III
INTRODUCTION

During the past twenty years pollution control for sinter plants has consisted of removing particulate matter in rotoclones or cyclones in the exhaust gas circuit between the windboxes and the discharge stack. These devices have also been used to recover dust generated in the sinter cake breaker area.

The recirculation of sinter machine waste gas that has passed through the rotoclones or cyclones back to a hood above the sinter bed is a new technique for the removal of combustibles and a portion of the particulate matter prior to discharge via a stack to atmosphere.

The objective of this project is to develop a waste gas recirculation system to improve the environmental consequences of discharging sinter plant waste gases to the atmosphere. Primary goals for improvement include reduction of hydrocarbons, particulates, and the volume of waste gas.

Four National Steel Corporation Divisions have supported this development, namely, the Granite City, Great Lakes, and Weirton Operating Divisions and the Research and Development Division. Each of the operating divisions is confronted with similar emission problems because of the similarity of their sinter plants. Chronologically, this EPA contract was first awarded to the Great Lakes Steel Division, which began this program in cooperation with the Granite City Steel and Research and Development Divisions. The first part of the project

consisted of background surveys, field sampling and project preparation. At this juncture it became necessary for the Great Lakes Steel Division to install final pollution abatement equipment on their sintering plant. The timing of this requirement interfered with the development of the gas recirculation system at this location.

The contract was then transferred to the Weirton Steel Division which had a prior interest in this system, had followed the Great Lakes work, and had advanced to the design stage prior to the transfer. Subsequently, the Weirton Steel Division completed the second part of the project, which included the concept and design engineering, equipment selection, detail engineering, and preparation of the final report. The test system was installed on the No. 2 Sinter Strand at the Weirton Steel Division. Construction was completed July 28, 1975.

The background work for this project involved a study of sintering and pollution control techniques presently in common use throughout the steel industry and the evaluation of the pollution problem by sampling and analysis. This subsequently led to the design, specification, and installation of equipment.

The report also describes a test program to be used for the future evaluation of the gas recirculation system.

Figure 1, General Arrangement of System, illustrates the components in the gas recirculation system.

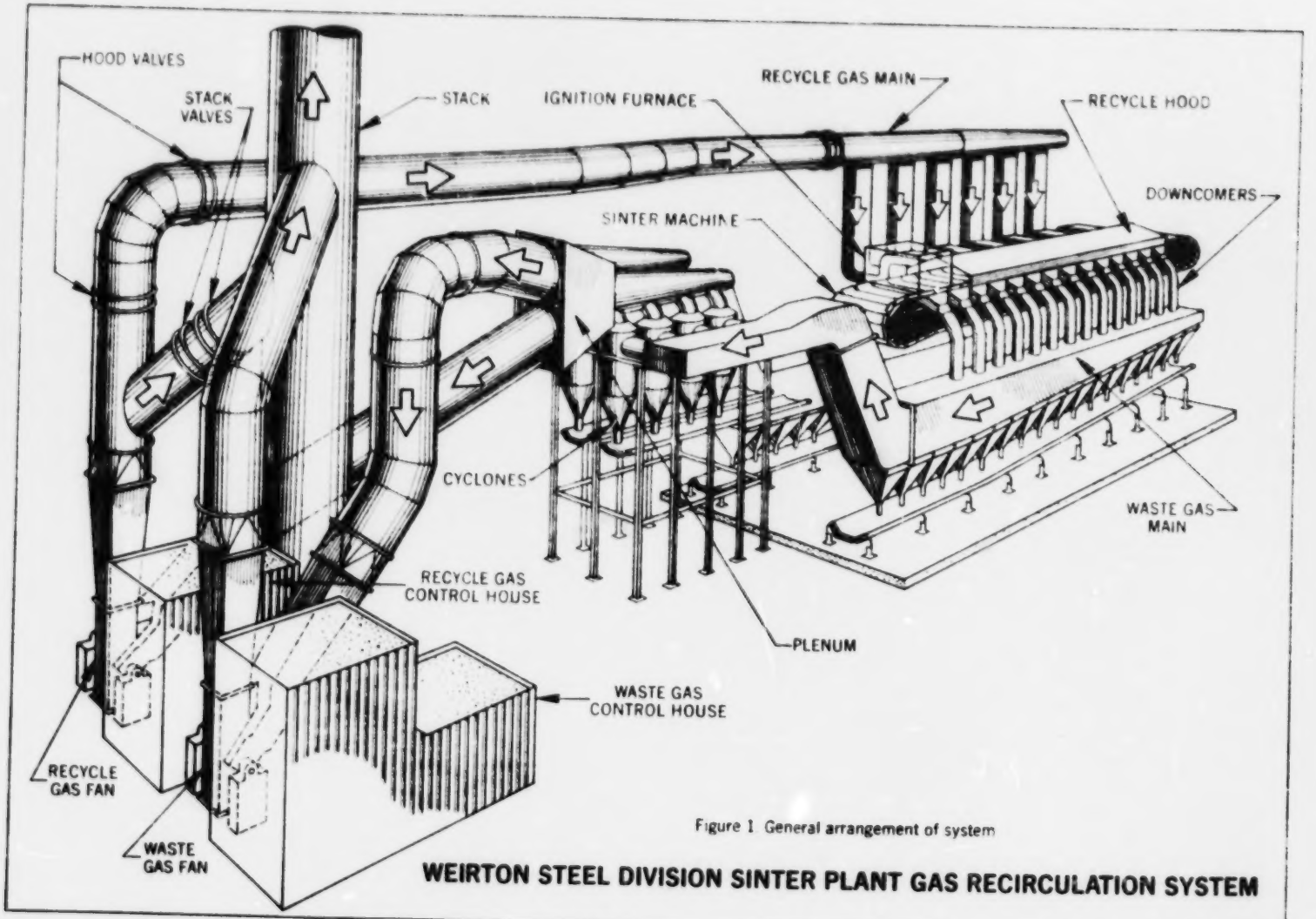


Figure 1 General arrangement of system

WEIRTON STEEL DIVISION SINTER PLANT GAS RECIRCULATION SYSTEM

SECTION IV
TECHNOLOGY REVIEW

INTRODUCTION

Sintering, as applied in the steel industry, may be defined as a process in which iron-bearing raw materials of a fine particle size are converted into coarse agglomerates by partial fusion. The product has a porous, cellular structure resembling clinker in physical appearance. Its mineralogy may be substantially different from that of the original iron-bearing fines.

Blast furnace sinter is categorized as acid or basic, depending on the basicity ratio*. Sinter with a basicity ratio of less than 1.0 is acid and that with a ratio greater than 1.0 is basic. It has become common to refer to sinter with a basicity ratio of approximately 1.0 as self-fluxing, while ratios in excess of 1.0 may be called burden-fluxing or super-fluxed sinter. Acid sinters of basicity less than 0.5 were predominant until the early 1950's. It was then realized that economic and productive benefits to the blast furnace could be realized by incorporating in the sinter a part or all of the required furnace flux. This was achieved by the addition of limestone and/or dolomitic fines to the ore fines to be sintered.

$$\text{*Basicity Ratio} = \frac{\text{Wt. Percent CaO + Wt. Percent MgO}}{\text{Wt. Percent } SiO_2 + \text{Wt. Percent } Al_2O_3}$$

PROCESS DESCRIPTION

In sintering, a shallow bed of fine particles is agglomerated by heat exchange and partial fusion of the quiescent mass. Heat is generated by the combustion of a solid fuel contained within the bed of fines being agglomerated. The process is initiated by igniting the fuel at the top surface of the bed, after which a thin, nigh temperature combustion zone is drawn downward through the bed by an induced draft. Within this zone, the surfaces of adjacent particles are at a fusion temperature and the gangue constituents form a semi-liquid slag. The flow of volatiles and incoming air creates a frothy condition and freezes the trailing edge of the advancing fusion zone. The product then consists of particles of ore bonded in a slag matrix of cellular structure.

In the ferrous industry, the material to be sintered consists essentially of a mixture of iron-bearing fines and a solid fuel. The iron-bearing constituents are chiefly iron ore fines, recycled sinter fines and blast furnace flue dust, but may also include mill scale, BOP dust and other steel mill waste products containing iron. Coke breeze is the most common solid fuel, but other carbonaceous materials are used. It has become common practice to add limestone or dolomitic fines to the sinter mix and this material may now be considered as an essential constituent in a typical sinter mix. This mixture of fine material is placed on the sinter strand in a shallow bed, seldom less than 152 mm (6 inches) nor more than 508 mm (20 inches) in depth. In the ignition zone, the surface of the bed is heated to about 1260 to 1371°C (2300-2500°F), combustion of the fuel is initiated, and fusion of the fine particles at the surface begins. As air is drawn through the bed, the high temperature zone of combustion and fusion moves downward through the bed and produces the bonded, cellular structure.

Combustion of the solid fuel and propagation of the fusion zone through the bed is dependent on the air flow. To assure an adequate air

flow, the sinter mix is generally preconditioned to improve its permeability. This can be accomplished by eliminating excessively fine materials when economically possible, but is normally achieved by the addition of coarse (12.7 mm by 3.2 mm [1/2 inch by 1/8 inch]) sinter returns and by fluffing and/or micropelletizing the fine particles in a balling drum.

PLANT FLOW DIAGRAM

The design and physical arrangement of sintering equipment and the flow pattern of raw materials and product differ considerably between various plants. The choice of equipment and material flow is generally determined by the desired capacity, space available, capital costs and prevailing technology. However, each plant can be divided into three distinct phases of operation, namely, (1) raw materials processing, (2) sinter production and (3) product processing. A schematic flow diagram of a typical modern sinter plant is shown in Figure 2.

The inbound raw ore is first screened to the maximum size desired for the blast furnace coarse ore. The oversize ore is then crushed. After a second screening at 9.5 to 12.7 mm (3/8 to 1/2 inch), the oversize is sent to the blast furnace stock house and the undersize is conveyed to the sinter plant storage bins. A separate raw materials system handles the balance of the materials, such as flue dust, limestone, coke breeze, mill scale, etc. Except for the coke breeze, these materials are sufficiently fine for sintering and are conveyed directly to the sinter plant storage bins. The coke breeze is usually ground in a rod mill prior to storage, although other size reduction techniques are sometimes used. Most modern plants are so arranged that the various screens, crushers, etc., can be bypassed if not required. From the raw materials storage bins, the desired materials are fed at a specified rate onto a common collector belt. Included in this material are the hot and cold

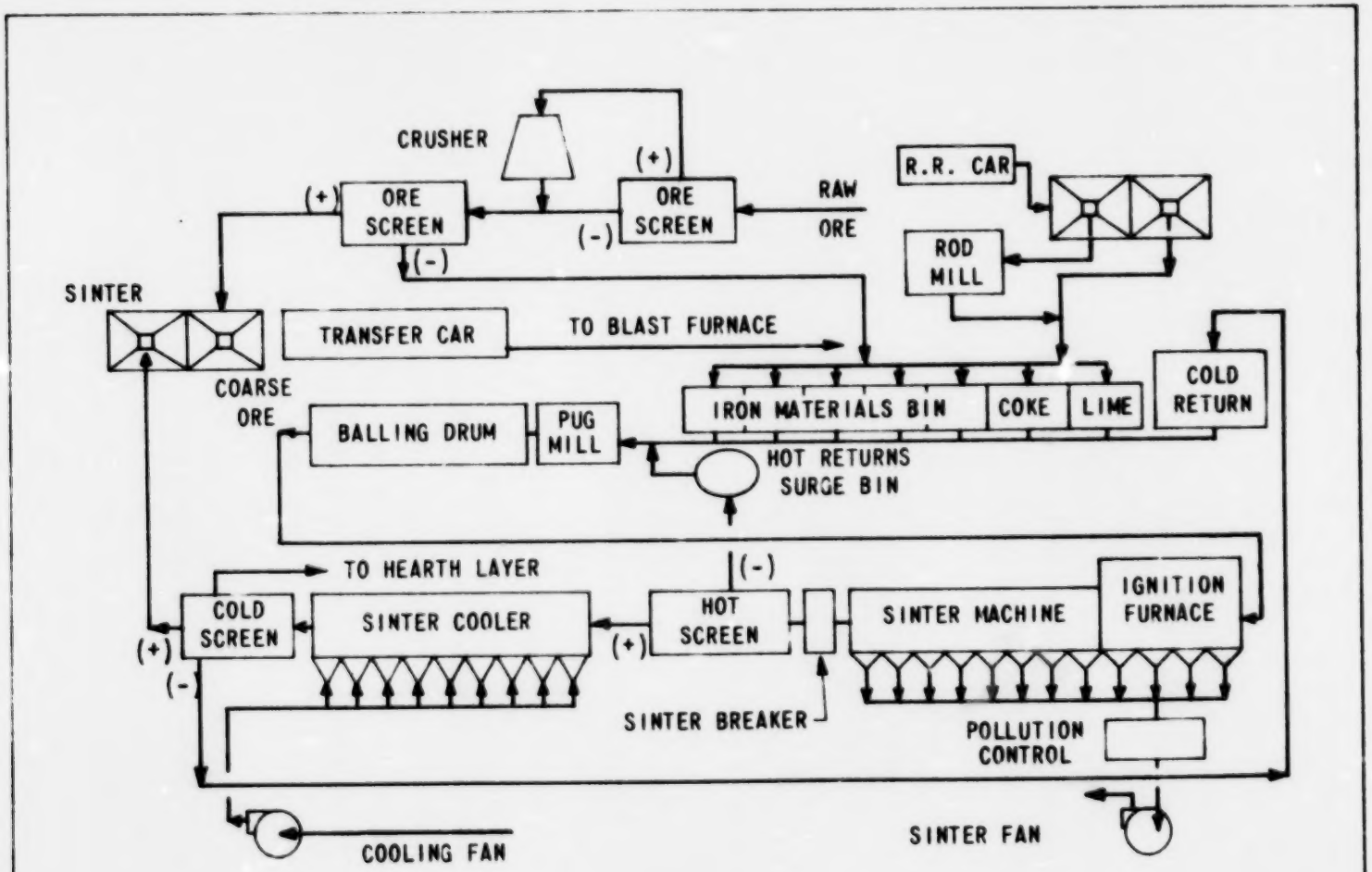


Figure 2. Schematic flow diagram for typical modern sinter plant

sinter return fines, generally fed from storage bins. Some plants do not have storage or surge capacity for hot returns, while others may be capable of adding the return fines at a later stage in the raw materials processing. The feed materials are then generally fed to a mixer, commonly a pug mill or a belt mixer. Some plants utilize only mixers, while other plants use pelletizing discs or drums which promote both mixing and micro-balling. Moisture for proper conditioning of the feed is added in the mixer and/or balling facility. The mixed and micro-pelletized feed is then conveyed to the sinter strand.

The sinter production phase of the operation occurs entirely on the sinter strand. Prior to feeding the raw mix, a grate layer of intermediate size sinter, usually finer than 25.4 mm (1 inch) and coarser than 6.35 mm (1/4 inch), is fed onto the machine grate to a depth of 25.4 to 50.8 mm (1 to 2 inches). This is done to reduce the temperature to which the grate bars are exposed, which extends grate bar life, and to reduce the amount of fine material passing through the grate bars. The raw mix is fed directly onto the grate layer to a predetermined bed depth and ignited in the ignition furnace fired with gas or oil. Once ignited, the induced draft draws the combustion zone down through the material bed. The process is complete when the combustion zone has burned through to the grate layer. The speed of the machine is controlled so that the burn-through reaches the grate layer as the material is ready to pass over the discharge end of the machine. The proper speed is determined by observing the sinter bed at the machine discharge and monitoring the maximum waste gas temperature in the next to last windbox.

Product processing begins at the discharge of the strand where the large cakes of sinter pass through a rotary breaker. The large cake is reduced to a maximum size of 203 to 305 mm (8 to 12 inches) to facilitate cooling. The fines generated from this crushing operation are removed by a hot screen and recycled to the raw mix feed, while the

oversize is sent to the cooler. There are several types of coolers, all of which function to reduce the temperature of the sinter so that it may be subsequently handled without damage to the conveying equipment. After the cooler, the sinter is cold screened, usually into three size consists. The smallest size consist, usually minus 9.5 mm or 6.35 mm (3/8 inch or 1/4 inch), is recycled as cold return fines. A portion of the intermediate size is recycled as grate layer. The excess over the grate layer needs is sent to product storage. The coarsest size is the preferred product for blast furnace feed. A large bin capacity is usually provided for loading out the sinter for the blast furnace stock house bins or storage yard.

These process and material flow descriptions are typical of a modern sinter plant and essentially describe the Great Lakes sinter plant. Many of the older plants lack certain features, such as hot and/or cold screens, balling facilities, sinter breakers, coolers, and flexibility in materials handling. Some of the newest plants may have special features for additional process control such as:

1. Raw materials proportioning systems. Raw materials bins may be equipped with controllable weigh feeders to maintain a constant weight proportionality for feed materials. This stabilizes the process and reduces the variation in product chemical composition.

2. Crushing of hot returns. This provides additional control over the size of hot returns which must be recycled.

3. Crushing of sinter prior to cold screening. This provides a closely sized product for blast furnace consumption and improves the final product strength by degrading the weaker particles prior to cold screening. However, this increases the quantity of material which must be recycled. In some cases, the oversize sinter from an initial cold screening is crushed, with a subsequent

secondary screening to remove the fine material generated.

4. Preconditioning of feed materials. Special circuits may be used to condition fine materials, such as steelmaking dusts, blast furnace filter cake and internal dusts from the sinter plant prior to introducing these materials into the main sinter mix.

5. On-strand cooling. The length of the sinter strand is increased so that some or all of the normal cooling is done on the strand rather than in a separate cooler. This eliminates the hot screening operation, although the single facility may be more complex.

6. Computer control of the process. Computers are used for process control in a number of foreign sinter p ants and in at least two domestic plants.

Of these, items 1, 3 and 6 are the most commonly encountered new features, with item 4 gaining importance as the incentive and need to recycle fine iron-bearing waste materials is accented.

MODE OF SINTER PLANT OPERATION

Most sinter plants are generally operated in a similar manner, differing primarily in the characteristics of the raw materials which must be processed and the basicity ratio chosen for the sinter product. The method of operating the sinter process and the effects of operating variables have been reported in the literature (1,2)*.

The general trend in materials used for sintering has been toward less iron ore fines and more iron-bearing waste materials such as mill scale, ironmaking dusts and slags. Fluxstone additions have increased

*See Section VIII, References.

TABLE I

MATERIALS USED IN THE PRODUCTION OF SINTER AT STEEL PLANTS IN THE UNITED STATES

MATERIAL		Year 1960	1964	1968
Iron Ore	a)	35,900	39,370	33,170
	b)	36,500	40,000	33,700
	c)	74	69	64
Flue Dust & Sludge		5,200	4,530	3,050
		5,300	4,600	3,100
		11	8	6
Scale		980	2,170	3,150
		1,000	2,200	3,200
		2	4	6
Cinder and Slag		49	394	394
		50	400	400
		.01	1	1
Other		490	1,080	1,770
		500	1,100	1,800
		1	2	3
Fluxstone		3,740	5,800	7,480
		3,800	5,900	7,600
		7	10	15
Fuel		2,360	3,250	2,660
		2,400	3,300	2,700
		5	6	5

a) Thousands of metric tons
b) Thousands of gross tons
c) Percentage of mix

with the trend toward higher sinter basicities. Table 1 shows the trend in sinter feed materials between 1960 and 1968 (3). The increased use of mill scale, cinder and slag, other materials which are primarily recyclable iron-bearing fines, and fluxstone is evident. The reduction in the use of blast furnace flue dust and sludge is due to improved blast furnace burdens.

A major factor influencing sinter plant operation has been the trend toward higher sinter basicities. In 1962, only about 40 percent of the sinter produced had a basicity ratio in excess of 1.0 (4). At the present time, available data indicate that at least 85 percent of the sinter produced in the United States and Canada has a basicity in excess of 1.0 (5). Moreover, at least six sinter plants regularly produce sinter with a basicity ratio greater than 3.0 and one plant in excess of 4.0. Increasing the sinter basicity generally reduces production capacity but increases the strength of the sinter product. Improved sinter quality reduces the quantity of fines to be recycled in the sinter plant and decreases the flue dust and sludge generated at the blast furnace. Higher basicity sometimes improves sinter strand operation and reduces the production and emission of fine dusts. However, higher basicity makes the choice of pollution control equipment more difficult (6).

NATIONAL STEEL FACILITIES AND PRACTICE

The process flow sheet for both the Great Lakes and Weirton No. 2 sinter plants is similar to that shown in Figure 2 except that neither plant has hot returns surge capacity. The Weirton No. 1 sinter plant has no hot returns surge capacity and has a primary and secondary pug mill rather than a balling mill. The Granite City sinter plant differs from the Figure 2 flow sheet in that it has none of the following:

1. No balling drum.

2. No hearth layer.

3. No hot returns surge bin.

4. No primary or secondary ore screens. All ores used for sinter feed must be pre-screened.

Table 2 gives the design data for the National Steel sinter plants.

Typical chemical compositions of raw materials used in the National Steel sinter plants are given in Table 3. However, the analyses may vary significantly for such iron-bearing waste materials as blast furnace flue dust, sludge and BOP dust. Individual ores may also vary significantly in composition but less so than the waste materials. In general, chemical uniformity is improved with beneficiation of the ores. Fluxstone and mill scale are generally the most chemically uniform materials in the sinter mix. Coke breeze chemistry is dependent upon the composition of the coals and the coal mix employed at the coke plant. Feed coal and coke plant practice affect coke breeze composition. Good sinter strand operation requires control of the carbon fuel. Therefore, the carbon content in the coke breeze, flue dust and sludge can significantly influence the sintering process.

The average composition of the sinter mix used at Great Lakes in 1972 and the first six months of 1973 and at Weirton No. 2 Strand in 1973 and 1974, is given in Table 4. The primary difference between 1972 and 1973 at Great Lakes is the increased fluxstone usage required to obtain the desired increase in sinter basicity. This, in turn, has decreased the proportion of ore and mill scale in the sinter mix. The Great Lakes sinter plant commenced operations in 1958 and since then the sinter mixes have changed in the same manner as indicated in Table 1. The

Table 2. NATIONAL STEEL SINTER PLANT DESIGN DATA

Design	Weirton No. 1
1) Built and designed by	Koppers, 1953
2) Active grate area	72.3 m^2 (832 ft^2)
length	31.7 m (104 ft)
width	2.3 m (8 ft)
3) No. of windboxes	13
4) Speed range	0.01-0.06 m/s (2-12 fpm)
5) No. of pallets	103
6) Size of pallets	0.61 m x 2.4 m (2 ft x 8 ft)
7) Height of sideboards	0.30 m (1 ft)
8) No. of grate bars/pallet	17
9) Analysis of grate bars	27-30 Cr 3-17% - 2 Ni
10) Ignition furnace type fuel	Arched hood Coke oven gas 580 kJ (550 Btu)
volume fuel	0.273 m^3/s (35,000 ft^3/hr)
11) Tempering hood	6.1 m (20 ft)
12) I.D. fans (a) No./Volume	1/99.12 m^3/s (210,000 cfm)
(b) Temperature	149°C (300°F)

Table 2. (continued)

Weirton No. 2	Great Lakes	Granite City
Koppers, 1958	Koppers, 1958	McKee, 1959
163.9 m^2 (1764 ft^2)	222.6 m^2 (2396 ft^2)	95.1 m^2 (1024 ft^2)
44.8 m (147 ft)	60.8 m (199 ft 6 in)	39.0 m (128 ft)
3.7 m (12 ft)	3.7 m (12 ft)	2.4 m (8 ft)
14	19	16
0.025-0.076 m/s (5-15 fpm)	0.025-0.102 m/s (5-20 fpm)	0.02-0.07 m/s (3.3-13.2 fpm)
110	138	95
1.07 m x 3.7 m (42 in x 12 ft)	1.07 m x 3.7 m (42 in x 12 ft)	
0.46 m (18 in)	0.46 m (18 in)	0.36 m (14 in)
162	162	
27-30 Cr 1-1/2 - 2 Ni	27-30 Cr 1-1/2 - 2 Ni	27-30 Cr 1-1/2 - 2 Ni
Arched hood Coke oven gas 580 kj (550 Btu) 0.488 m^3/s (62,000 ft^3/hr)	(2) flat roof Coke oven gas 580 kj (550 Btu) 1.49 m^3/s (190,000 ft^3/hr)	Arched hood Coke oven gas 580 kj (550 Btu)
8.5 m (28 ft)	None	None
2/132.16 m^3/s 280,000 cfm) ea	2/162.37 m^3/s (344,000 cfm) ea	1/132.16 m^3/s (280,000 cfm)
177°C (350°F)	177°C (350°F)	149°C (300°F)

Table 2. NATIONAL STEEL SINTER PLANT DESIGN DATA (continued)

Design	Weirton No. 1
(c) Vacuum	762 mm wc (30 in)
(d) Speed	712 rpm
(e) Motor	1492 kW (2000 hp)
13) Sinter breaker	Yes
14) Cooler	Straightline
(a) Length	45.7 m (150 ft)
(b) Width	1.5 m (5 ft)
(c) Speed range	0.01-0.06 m/s (2-12 fpm)
(d) Cooler fans	
No./Volume	3/38.9 m^3/s (82,500 cfm) ea
Pressure	203 mm wc (8 in)
Temperature	Ambient
15) Hot screens	Stationary grizzly
No./Size	
Deck	SAE 4130 (25mm)
16) Cold screens	W. S. Tyler
Size	FB80 - 3.3 m x 3.0 m (11 ft x 10 ft)
Deck	Rod deck

Table 2. (continued)

Weirton No. 2	Great Lakes	Granite City
1016 mm wc (40 in)	1016 mm wc (40 in)	762 mm wc (30 in)
712 rpm	900 rpm	900 rpm
1865 kw (2500 hp)	3357 kw (4500 hp)	1492 kw (2000 hp)
Yes	Yes	Yes
Straightline	Straightline	Circular
45.7 m (150 ft)	54.4 m (178 ft 6 in)	14.6 m dia. (48 ft)
3.0 m (10 ft)	3.0 m (10 ft)	-
0.025-0.076 m/s (5-15 fpm)	0.025-0.076 m/s (5-15 fpm)	0.03-0.097 m/s (6-19 fpm)
2/120.36 m^3/s (255,000 cfm) ea	3/100.1 m^3/s (212,000 cfm) ea	3/23.6 m^3/s (50,000 cfm) ea
152 mm wc (6 in)	152 mm wc (6 in)	178 mm wc (7 in)
Ambient	Ambient	Ambient
H-R 2/1.5 m x 6.1 m (5 ft x 20 ft)	H-R 2/1.5 m x 6.1 m (5 ft x 20 ft)	H-R 1/1.5 m x 6.9 m (5 ft x 22 ft 6 in)
SAE 4130 (Mod)	HC 250	USS T-1
W. S. Tyler	W. S. Tyler	W. S. Tyler
F900 - 1.8 m x 3.7 m (6 ft x 12 ft)	F900 - 1.8 m x 3.7 m (6 ft x 12 ft)	1.8 m x 3.7 m (6 ft x 12 ft)
Cast manganese	HC 250	Rod deck

Table 3 CHEMICAL COMPOSITIONS OF NATIONAL STEEL RAW MATERIALS
(dry basis - %)

Material	Constituent								
	Iron	SiO_2	Al_2O_3	CaO	MgO	Mn	Phos	Sulfur	Free Carbon
Ore A	57.71	9.55	0.72	0.10	0.18	0.76	0.049	0.005	-
Ore B	59.37	7.30	1.56	0.03	0.04	0.57	0.097	0.008	-
Ore C	47.81	17.87	1.11	0.56	0.17	4.91	0.056	0.008	-
Ore D	61.01	11.29	0.57	0.10	0.05	0.01	0.010	0.015	-
Fluxstone A	0.42	0.19	0.31	30.32	22.26	-	-	0.061	-
Fluxstone B	0.45	1.11	1.42	51.61	1.31	-	-	0.098	-
Fluxstone C	0.45	1.38	1.27	45.24	7.83	-	-	0.032	-
Fluxstone D	0.11	1.28	0.18	30.16	21.09	-	-	0.016	-
Flue dust A	40.06	6.10	1.42	4.39	0.80	0.60	0.102	0.27	26.55
Flue dust B	47.77	4.55	1.66	4.06	2.48	0.46	0.072	0.31	17.40
Sludge A	42.55	6.78	1.23	3.87	1.95	0.56	0.136	0.36	18.89
Sludge B	42.11	7.86	2.03	3.21	2.25	0.41	0.041	0.45	19.40
Mill scale A	72.90	1.43	0.69	0.17	0.16	0.73	0.096	0.038	-
Mill scale b	72.46	0.42	0.18	0.65	0.43	-	-	0.031	-
Coke breeze A	4.40	3.97	1.95	4.65	0.44	0.010	0.010	0.63	71.0
Coke breeze B	2.99	5.01	2.23	0.06	0.47	-	-	0.92	81.2
BOP dust A	54.50	2.35	0.10	8.00	1.70	1.20	0.130	0.050	0.60

Note: The values shown are after completion of sintering process & do not reflect moisture, oxygen, total carbon, hydrocarbons & trace elements.

Table 4. SINTER MIXES - YEARLY AVERAGE
(weight %)

Constituent	Great Lakes		Weirton No. 2 Strand	
	1972	1973	1973	1974
Ore	55.3	54.0	59.50	65.16
Mill scale	10.9	10.7	3.53	3.84
Flue dust	2.2	2.7	1.02	0.16
Sludge	1.4	0	1.40	1.54
Fluxstone	24.4	26.5	28.45	22.80
Coke breeze	5.8	6.1	6.10	6.50
Sinter basicity	1.96	2.06	2.25	1.73

increase in mill scale usage shown in Table 1 is due to increased steelmaking capacity and improved mill scale recovery. Mill scale is seldom purchased from outside sources at Great Lakes. Increased sinter basicity has increased fluxstone consumption, while improved blast furnace burdens have reduced the quantity of flue dust and sludge which must be recycled. BOP dust is not presently consumed.

The primary difference between Weirton No. 2 Strand operations for 1973 and 1974 is the reduced fluxstone consumption, resulting in lower sinter basicity. This is a result of materials handling limitations and not a desire to operate at low basicity rates. The amount of fluxstone that can be introduced is limited and 1974 reflects a two plant (Strand No. 1 and No. 2) operation versus 1973's single plant (Strand No. 2) operation.

FUTURE PRACTICES AFFECTING SINTER PLANT EMISSIONS

There are at least four trends in current operating practices that could alter sintering process emissions. The trend toward higher sinter basicity will affect both sinter strand operation and sinter quality. Limited experience and laboratory tests indicate that sinter strength increases at the 3.0 sinter basicity envisioned for future sinter plant operation. This would result in a decrease in blast furnace flue dust and possibly sludge which are recycled to the sintering process. Limited experience also indicates a more stable sinter strand operation at the 3.0 basicity level, which should reduce emissions. While there may be a slight reduction in hot and/or cold returns generation, it is doubtful whether this would significantly influence strand operation. The net effect of higher basicity sinter should be a reduction in emissions, although the particulate matter will probably be higher in basic content.

A second trend which will influence future sinter plant emissions is the increased use of in-plant iron-bearing waste materials. The variation in the chemical composition of these materials will make control of sinter chemistry more difficult. More important, from an emissions standpoint, is the size consist of these materials. Since most of these waste materials will be the byproducts of other pollution control facilities, they will be fine in size, particularly with respect to the proportion of material finer than 100 mesh. Unless properly combined into the sinter mix, the fine fractions will reduce bed permeability and make process control more difficult. The net effect of increased fine materials usage is the potential for increased particulates in the waste gas if proper operating conditions are not achieved. This includes uniform distribution throughout the mix to prevent concentrated areas of poor sintering characteristics and adequate micro-balling of the mix to achieve good bed permeability.

The third trend influencing future sinter plant practice is directly related to the aforementioned problem of increased fine particles and involves preconditioning of fine waste materials prior to use in the sinter mix. This is already practiced in some foreign countries, notably Japan, where BOP dust is micro-pelletized to achieve suitable handling characteristics. Another method of conditioning is premixing of all waste materials prior to addition to the sinter mix. By using a separate mixing circuit, improved proportioning of these materials is often achieved. Micro-pelletization may be enhanced with the appropriate equipment and mixtures of waste materials can be handled with less tendency to become airborne. The mixture will be more uniformly dispersed throughout the total sinter mix by subsequent mixing facilities. The net effect is to improve sinter plant operation, reduce the tendency for in-plant airborne dusting and minimize emissions.

A fourth factor which could significantly affect future sinter plant operation and emissions is the process of waste gas recirculation.

Batch laboratory tests simulating waste gas recirculation have indicated that sinter quality can deteriorate if the oxygen in the waste gas recirculated to the sintering process is less than some minimum value. This minimum oxygen value appears related to the raw materials mixture being processed and possibly to the specific process operating conditions. Whether this minimum value is reached depends on the specific sinter plant and mode of waste gas recirculation employed. Limited application of waste gas recirculation to continuous commercial and pilot sintering facilities indicates a reduction in particulate and condensable organic emissions. It is certain that the final level of emissions that is achieved will be partially dependent on the stability of the sinter strand operation.

SECTION V
BASELINE MEASUREMENTS

INTRODUCTION

This section presents a compilation of field testing data and related sinter plant production information for an existing sintering facility selected to develop the design for a gas recirculation system. The primary field testing for this project was conducted at Great Lakes Steel's No. 2 Sinter Plant. This production facility is located on Zug Island in the city of River Rouge, Michigan. Zug Island is situated approximately 4-1/2 miles southwest of the main business district of the city of Detroit.

Field sampling was conducted under various operating conditions at three locations in the plant. Windbox gases were sampled at the main stack, as were gases generated at the sinter breaker and hot screen areas. As mentioned in Section III, this project was transferred from the Great Lakes Steel to the Weirton Steel Division for completion. Field test data obtained by the Weirton Steel Division prior to the transfer are presented in Appendix A. These data are qualified because of the different sampling techniques used. However, the same fundamental parameters (hydrocarbons, particulate, and oxygen content) necessary to evaluate the merits of gas recirculation, as well as other required system design data, were obtained.

TESTING PROCEDURE

These tests were conducted on the main exhaust stack and on breechings to another stack which serviced in-plant clean-up. The main stack samples represented combustion gases generated directly from the sintering process. Emissions tests were also conducted at the machine discharge area, particularly at the sinter breaker and hot screens, to determine if these gases could be used to enrich the oxygen content of the windbox recirculated gas, should that become necessary to prevent starving of the combustion process because of too lean a recycled gas.

Tests were conducted on various sinter mixes at different production rates to define the parameters affecting quality of the generated gases. Gas flowrates and temperatures were monitored throughout the testing period. Fan amperages and speeds were monitored to maintain steady state operation of the exhaust systems under various production conditions. Gas composition and particulate loading including condensables were determined as a result of this field testing program. Figure 3 is a plan view of the No. 2 Sinter Plant showing the field sampling locations.

Gas Flowrate Determinations

Pitot tube traverses were conducted at each pertinent sampling site by dividing the stack or breeching into equal areas. The mid-points of these areas were measured with an "S" type pitot tube and an inclined manometer in accordance with procedures in the American Conference of Governmental Industrial Hygienists Industrial Ventilation manual. Gas velocities were monitored during the sampling intervals using pitot tube measurements. The sampling rate was then adjusted, when necessary, to assure isokinetic sampling.

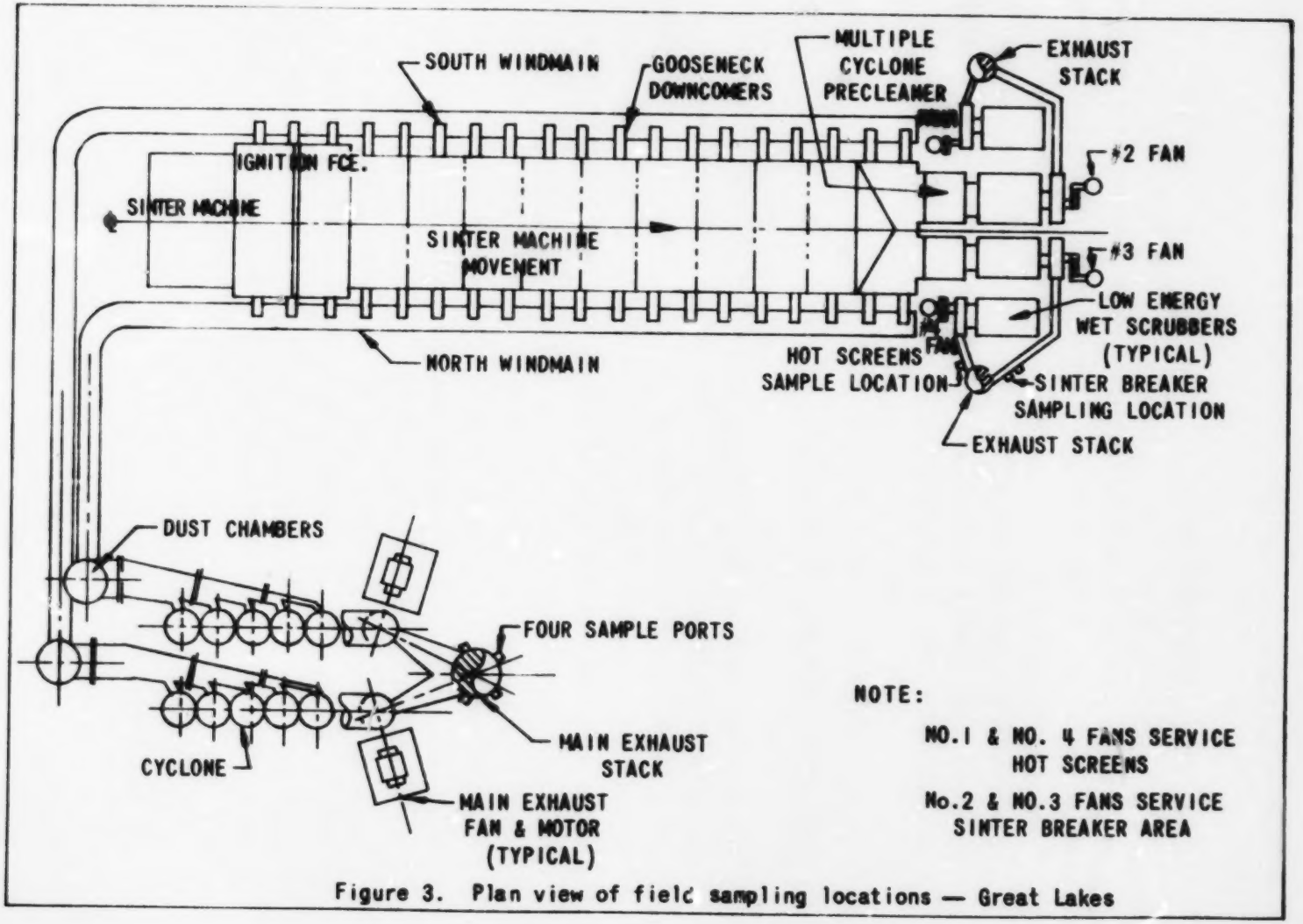


Figure 3. Plan view of field sampling locations — Great Lakes

Miscellaneous Determinations

Gas temperatures in the main stack and ductwork were recorded periodically during each sampling interval. Gas temperatures and pressures, from gages located on the dry gas meters and vacuum pumps, were also recorded during the sampling period. These data were then used to determine dust loading values. Gas temperatures were further monitored by personnel periodically gathering gas samples.

Particulates and Condensables Determinations

The sampling train, shown in Figure 4, was used for collecting particulates and inorganic and organic condensables. The fiberglass filter, shown in the sampling train, removed the particulate emissions during testing. The quantity of particulate on the filter and the flow data collected during testing were used as the basis for all particulate emission calculations.

The first two impingers in the sampling train, each containing distilled water, removed the organic and inorganic condensables during testing. The condensable concentrations were then separated into organic and inorganic components by determining the quantity soluble in petroleum ether. The organic and inorganic condensables collected in the impingers and the flow data collected during testing were used as the basis for all condensable emission calculations.

SO_X Determinations

Sulfur oxides were collected by the sampling train shown in Figure 5. The gaseous sulfur compounds, consisting primarily of sulfur trioxide

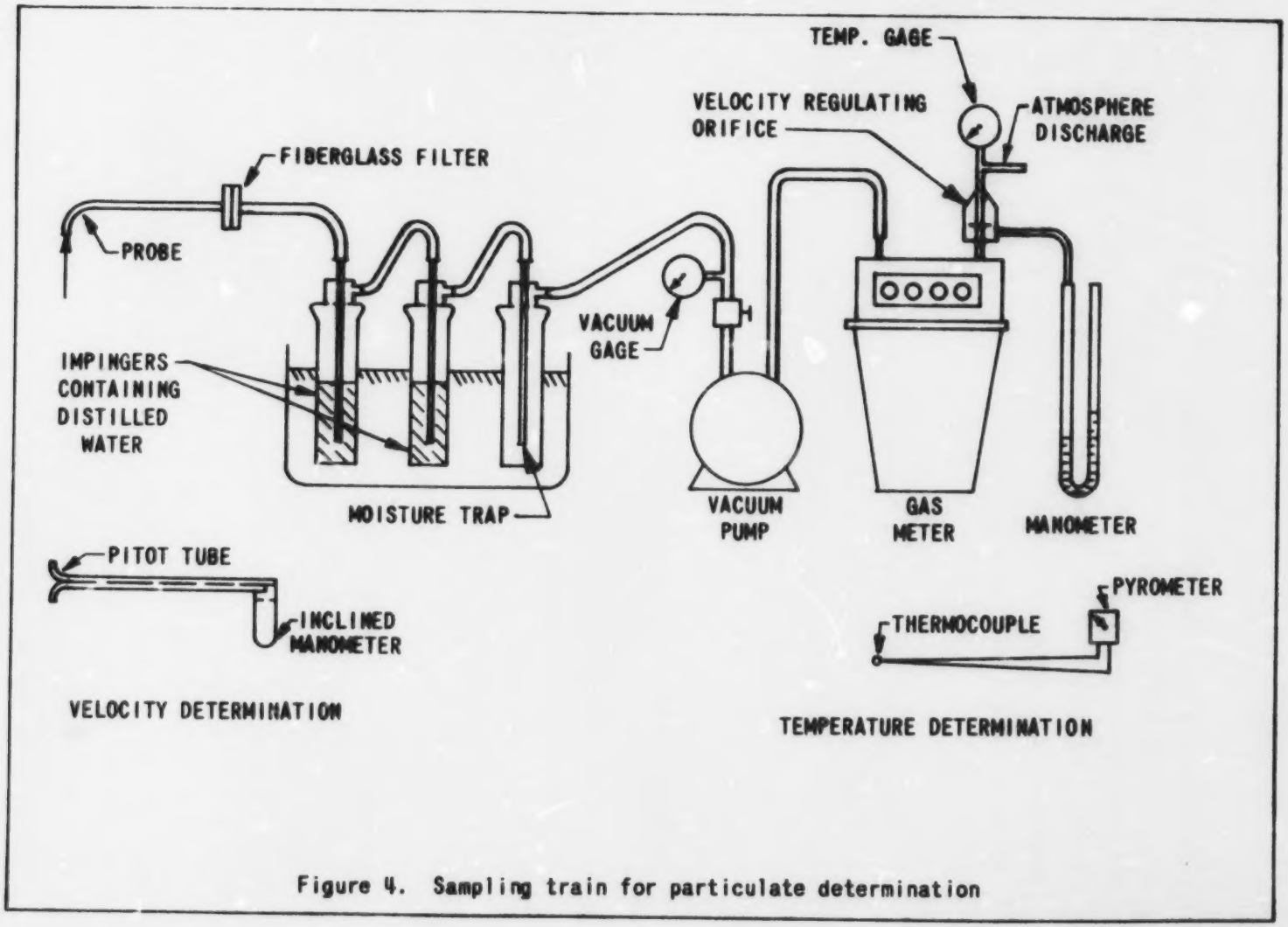


Figure 4. Sampling train for particulate determination

and sulfur dioxide, were collected separately, using isopropyl alcohol and alkaline hydrogen peroxide. A filter in the sampling train removed the filterable particulates. The first impinger, containing isopropyl alcohol, collected the sulfur trioxide component from the gases. The gases were then scrubbed through two Greenberg-Smith series connected impingers containing 0.1 N NaOH and 5% hydrogen peroxide. The gas stream was then metered according to the attached arrangement.

All the impinger samples were returned to the laboratory and analyzed using barium chloride. The barium sulfate precipitates were weighed and appropriate blanks were run for both the isopropyl alcohol and alkaline peroxide solutions.

Oxides of Nitrogen Determinations

Round bottomed glass flasks were used to collect samples of the exhaust gas. These flasks, containing concentrated sulfuric acid and hydrogen peroxide, were first evacuated of air in a control room situated near the testing sites. The method for evacuating these flasks is shown in Figure 6.

The evacuated flasks were then connected to the sampling train, also shown in Figure 6. Samples of the gas were drawn through the train for a time sufficient to flush the lines completely of air and to fill them with exhaust gas. The vacuum pump was then shut down and the evacuated flash exposed to the stack gases by opening the flask stop cock. The gases were then collected in the initially evacuated flask. The stop cock was then closed, the opening sealed, and the entire flask sent to the laboratory for analysis. The samples were analyzed for total oxides of nitrogen, using phenol-disulfonic acid. Standard curves were prepared for calibration, using a known quantity of sodium nitrate.

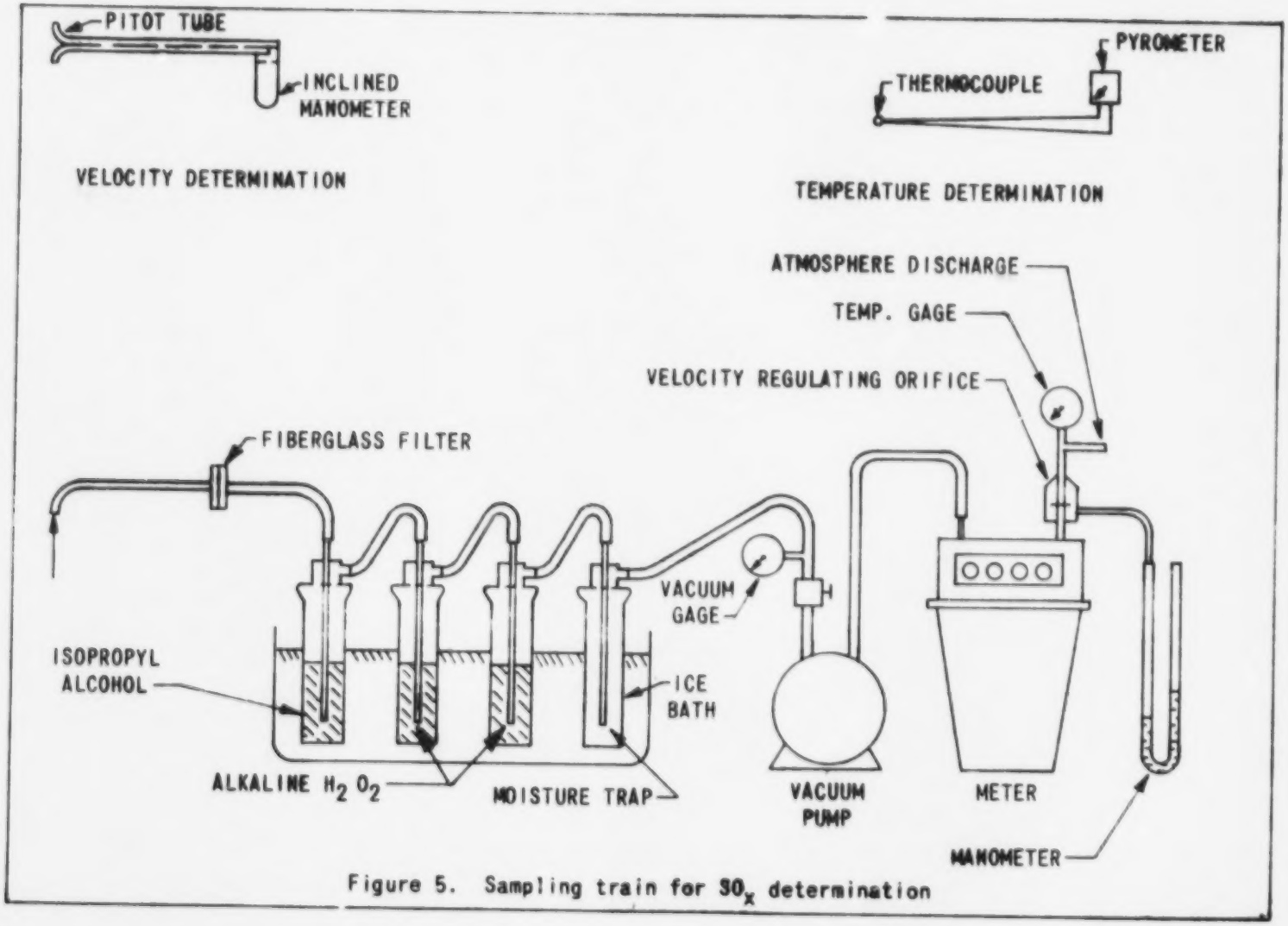
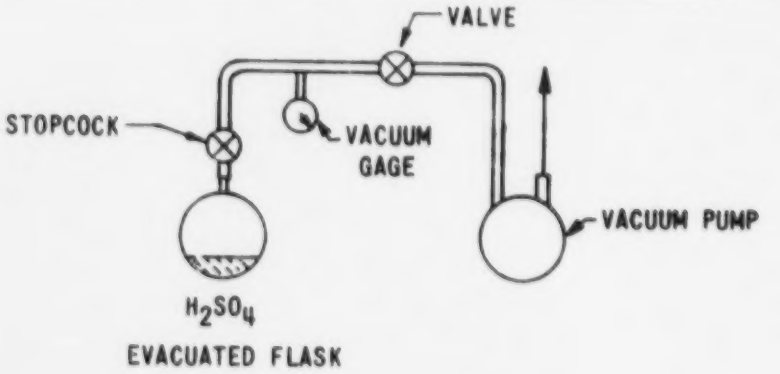


Figure 5. Sampling train for SO_x determination



METHOD OF PREPARATION
FOR EVACUATED FLASKS

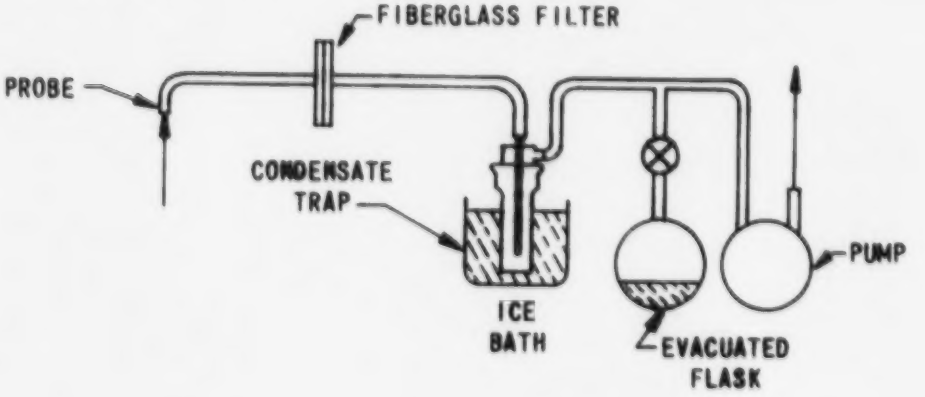


Figure 6. Sampling system for oxides of nitrogen determination

Gas Composition Determinations

Gas samples were obtained periodically throughout a given sampling day. Gas temperatures were also taken to monitor the gas exhaust system. The samples were taken by placing a stainless steel probe within the stack or ductwork and connecting it to a Pyrex gas collecting bottle. The other side of the bottle was connected to a vacuum device to purge the system of air. Exhaust gas filled the gas collecting bottle. Stop cocks located at each end of the bottle were closed and the ends sealed.

The gas samples were then taken to the chemical laboratory for the analysis of hydrogen, nitrogen, carbon monoxide, carbon dioxide, and oxygen (by difference), using a Perkin-Elmer Gas Chromatograph, Model 990, Hot Wire Detector. The chromatograph was calibrated using a premixed gas of similar composition to those gases being analyzed.

TESTING DISCUSSION

General

Field sampling and testing was conducted at Great Lakes Steel's No. 2 Sinter Plant facility in October, 1973. This was done to gather additional information about important operating parameters needed to properly design a gas recirculation system. Field testing, conducted under various operating conditions, yielded information on gas composition, dust loading, and temperature variations. These field tests have helped in identifying and quantifying the main exhaust stack emissions, including sintering process combustion gases, and the sinter breaker and hot screen discharge area emissions.

Information presented in this field sampling report includes the following:

A measure of materials comprising the sinter feed.

System operational data for control of the process.

An analysis of gaseous emissions, including gaseous pollutants and those which affect sinter plant operation.

Particulate loading concentrations and chemical analyses of collected dust, including a summary of testing results.

Discussion follows on each of the above items to improve understanding the sintering process and its related gaseous emissions. Projections can then be made of foreseeable trends that might cause deviation from current operating practice and might alter the emissions generated by the sintering process.

Plant Operation and System Control

Field sampling was conducted during three weeks of sintering. Each week a separate production rate and sinter product basicity rating was selected to evaluate the system generated dust loadings under various operating conditions.

Table 5 presents plant production data taken during the field sampling periods. Although field sampling generally was conducted during the day turns, additional production data for the other shifts and total daily production figures are also presented to indicate the consistency of sinter production. The No. 2 Sinter Plant, where tests were conducted,

generally decreases sinter production as the sinter basicity increases. Throughout the weeks of testing, three separate production goals were selected with their respective sinter basicity in order to provide adequate fluxing product for the four blast furnaces located at Great Lakes Steel. The daily production goal for the first week of testing was set at 5200 mtpd at 2.0 basicity. The actual production data supports this goal. Each successive week, for two weeks, a lesser sinter production rate was selected. The sinter basicity was increased to 2.5 in the second week and then finally to 3.0 basicity in the final week. Table 5 also includes information about the sinter feed mix selected to develop the desired sinter production basicity.

The day after each week's testing period was selected by operating personnel as a down-turn period during which maintenance, general repair and clean-up of the plant took place. We observed that maintenance and clean-up generally increased as the sinter product basicity increased. This corresponds with the increasing dust content of the in-plant air as the production basicity increased.

Table 5. PLANT PRODUCTION DATA

DESCRIPTION	1ST WEEK TESTING			
	10-16-73	10-17-73	10-18-73	TEST PERIOD AVG.
SINTER PLANT PRODUCTION				
Turn No. 1 11-7 Shift mtpd (tpd)	1589 (1750)	1816 (2000)	1816 (2000)	1740 (1917)
Turn No. 2 7-3 Shift mtpd (tpd)	1816 (2000)	1816 (2000)	1531 (1687)	1721 (1896)
Turn No. 3 3-11 Shift mtpd (tpd)	1816 (2000)	1816 (2000)	1589 (1750)	1740 (1917)
Total mtpd (tpd)	5221 (5750)	5448 (6000)	4936 (5437)	5201 (5730)
AVERAGE SINTER BASICITY				
Turn No. 1 11-7 Shift	1.99	2.04	2.19	2.07
Turn No. 2 7-3 Shift	2.00	1.89	2.15	2.01
Turn No. 3 3-11 Shift	2.15	2.00	2.00	2.05
Average	2.05	1.98	2.11	2.05
SINTER MIX - % BASIS				
Hanna ore	17.0	17.0	13.4	15.8
Labrador ore	18.5	18.5	19.7	18.9
Moose mountain ore	-	-	-	-
Lauretta ore	8.5	8.4	8.9	8.6
Total ore mix	44.0	43.9	42.0	43.3
Scale	5.4	5.4	5.4	5.4
Flue dust	1.5	1.4	1.6	1.5
Sludge (filter cake)	-	-	-	-
Coke breeze	4.7	5.1	5.0	4.9
Limestone	9.7	9.7	10.2	9.9
Dolomite	9.7	9.7	10.2	9.9
TOTAL RAW MIX	75.0	75.2	74.4	74.9
Cold sinter returns	17.2	17.4	17.4	17.3
Hot sinter returns	7.8	7.4	8.2	7.8
TOTAL MIX	100.0	100.0	100.0	100.0

Table 5. (continued)

2ND WEEK TESTING				3RD WEEK TESTING		
10-22-73	10-23-73	10-25-73	TEST PERIOD AVG.	10-29-73	10-31-73	TEST PERIOD AVG.
1692 (1864)	1587 (1748)	1620 (1784)	1633 (1799)	1242 (1368)	1511 (1664)	1377 (1516)
1692 (1864)	1469 (1618)	1639 (1806)	1600 (1763)	1334 (1469)	1039 (1144)	1187 (1307)
1692 (1864)	1473 (1623)	1322 (1456)	1496 (1648)	1511 (1664)	897 (988)	1204 (1326)
5076 (5592)	4529 (4989)	4581 (5046)	4729 (5210)	4087 (4501)	3447 (3796)	3768 (4149)
2.34	2.35	2.38	2.36	2.55	2.91	2.73
2.53	2.18	2.01	2.24	2.96	2.87	2.92
2.54	2.37	2.46	2.46	3.34	2.83	3.09
2.47	2.30	2.28	2.35	2.95	2.87	2.91
12.8	11.9	12.4	12.4	8.5	10.8	9.6
18.4	17.8	18.2	18.1	15.2	14.9	15.1
-	-	-	-	-	-	-
8.5	8.8	9.1	8.8	9.9	9.2	9.6
39.7	38.5	39.7	39.3	33.6	34.9	34.3
5.4	5.4	5.7	5.5	6.1	6.1	6.1
1.5	1.5	1.1	1.4	-	1.4	0.7
-	-	-	-	-	-	-
5.0	5.0	4.8	4.9	5.6	5.4	5.5
9.3	9.2	9.3	9.3	8.5	8.3	8.4
13.6	13.6	11.7	12.9	16.7	15.9	16.3
74.5	73.2	72.3	73.3	70.5	72.0	71.3
17.8	18.5	19.1	18.5	20.7	19.5	20.1
7.7	8.3	8.6	8.2	8.8	8.5	8.6
100.0	100.0	100.0	100.0	100.0	100.0	100.0

Plant Operation and System Control (continued)

To monitor the system, several operating parameters were selected by the teams conducting the field testing. Table 6 presents daily averages of those monitoring parameters. For example, observation of the exhaust gas temperatures from the main exhaust stack, sinter breaker area and hot screens area indicates a general consistency of these parameters over the entire three-week testing period. On the other hand, the sinter breaker and hot screen exhaust gases fluctuated consistently around the daily values due to the variation in the water supplied to low-energy wet scrubbers ahead of the selected sampling locations.

Fan speed, motor speed and motor current are also shown in Table 6 for the entire discharge area in-plant gas cleaning system. Only the northwest half of this system, Fan Systems No. 3 and No. 4, were selected for actual field testing, owing to the limited manpower available for field and analytical work. The other two fan systems were monitored to assure to field personnel that samples obtained from each half of the system were consistent with those from the other half. Observation of the presented data shows this consistency. Fluctuations in the observed data resulted from manual injection of water to the scrubbers and from operating conditions beyond the control of the field testing teams.

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Table 6. SYSTEM OPERATIONAL DATA

DESCRIPTION	LST WELL TESTING				TEST PERIOD
	10-15-74	10-16-74	10-17-74	10-18-74	AVG.
[illegible]					
[illegible]		72	83	81	79
[illegible]		1195.3	1193.3	1179.9	1189.5
[illegible]					
[illegible]					
[illegible]	1610			1602	1611
[illegible]	1193			1193	1193
[illegible]					
[illegible]		83		49	61
[illegible]					
[illegible]	42	26	10	32	23
[illegible]	2501	2500	2501	2501	2501
[illegible]	1623			1600	1610
[illegible]	49			1195	1195
[illegible]					
[illegible]		60		50	55
[illegible]					
[illegible]	1620			1620	1620
[illegible]	1195			1195	1195
[illegible]					
[illegible]		104		61	83
[illegible]					
[illegible]	42	41	0	23	32
[illegible]	11581	11530	11511	11571	11551
[illegible]	5.13				5.13
[illegible]	1195				1195
[illegible]					
[illegible]		100		50	75

Table 6. (continued)

2ND WEEK TESTING				3RD WEEK TESTING		
10-22-73	10-23-73	10-25-73	TEST PERIOD AVG.	10-29-73	10-31-73	TEST PERIOD AVG.
74 (166)		88 (190)	81 (178)	81 (178)		81 (178)
	1656		1656		1600	1600
	1195		1195		1195	1195
90	100		95	80	73	73
32 (90)		36 (96)	34 (93)	32 (90)	33 (91)	33 (91)
	1633		1633		1645	1645
	1195		1195		1195	1195
67	70		69	70	63	63
	1633		1633		1667	1667
	1195		1195		1195	1195
70	70		70	73	68	71
50 (122)		38 (100)	44 (111)	36 (97)	27 (81)	32 (89)
	1661		1661		1645	1645
	1195		1195		1195	1195
93	100		97	72	60	66

Chemical Composition of Exhaust Gases

Tables 7, 8 and 9 present a detailed analysis of the chemical composition of the gases from the main exhaust stack, sinter breaker, and hot screens areas, respectively. The main exhaust gases are of paramount importance since they are the primary source for recirculation of gases back to the sinter machine. Generally, three field samples were taken of the main stack gases daily. The oxygen content of these gases averaged 16% by volume, with a variation of $\pm$ 2%. Further observation of Table 7 data does not reveal a definite pattern in the oxygen content as compared to sinter production variations. In fact, selection of any other gaseous composition indicates a relative uniformity independent of sinter production, as far as the main exhaust stack gases are concerned. This conclusion is based only on the variations of sinter production selected for the field testing periods.

Tables 8 and 9 indicate the same consistency for gases generated at the discharge area as that observed for main stack gases; that is, the consistency apparently is independent of production rate and sinter product basicity. The oxygen content of either gas stream from the discharge area is generally 20% with a variation of $\pm$ 1%. Review of the composition of the gases from the discharge area indicates that relatively little combustion occurs as the sinter is discharged from the pallets, broken into large pieces, and primarily classified at the hot screens area. Other than the presence of a small quantity of oxides of sulfur and nitrogen and the hot and dusty condition of the gas, these gases are quite similar to atmospheric air. On a gas composition basis only, these discharge area gases may be considered for usage in enriching the primary recirculation gases, should the latter stream become "too-lean" in oxygen content to adequately support combustion in the sinter burden.

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Table 7. MAIN EXHAUST STACK GAS COMPOSITION DATA

DESCRIPTION	1ST WEEK TESTING			
	10-16-73	10-17-73	10-18-73	TEST PERIOD AVG.
HYDROGEN - % BY VOLUME				
Test 1	1.02	0.89	1.07	0.99
Test 2	1.12	1.17	1.06	1.12
Test 3	1.12		1.15	1.14
Average	1.08	1.03	1.09	1.07
NITROGEN - % BY VOLUME				
Test 1	76.82	78.49	78.49	77.93
Test 2	76.82	80.16	77.85	78.28
Test 3	77.66		77.85	77.76
Average	77.10	79.33	78.06	78.16
CARBON MONOXIDE - % BY VOLUME				
Test 1	0.43	0.62	0.52	0.52
Test 2	0.25	0.62	0.39	0.42
Test 3	0.47		0.38	0.43
Average	0.38	0.62	0.43	0.48
CARBON DIOXIDE - % BY VOLUME				
Test 1	4.86	5.92	5.23	5.34
Test 2	3.97	5.59	4.99	4.85
Test 3	5.21		4.48	4.85
Average	4.68	5.76	4.90	5.11
OXYGEN - % BY VOLUME (BY DIFF)				
Test 1	16.87	14.08	14.69	15.22
Test 2	17.84	12.46	15.71	15.33
Test 3	15.54		16.14	15.82
Average	16.76	13.26	15.52	15.18
SULFUR TRIOXIDE - PPM BASIS				
Test 1	11.0	0.89	6.30	6.06
Test 2			6.40	6.40
Test 3				
Average	11.0	0.89	6.35	6.23
SULFUR DIOXIDE - PPM BASIS				
Test 1	0.61	1.34	0.34	0.76
Test 2			0.30	0.30
Test 3			0.27	0.27
Average	0.61	1.34	0.30	0.44
OXIDES OF NITROGEN - PPM AS NO_2				
Test 1	40.4	22.4	75.6	46.1
Test 2			85.7	85.7
Test 3			42.6	42.6
Average	40.4	22.4	68.0	43.6

Table 7. (continued)

2ND WEEK TESTING			3RD WEEK TESTING		
10-22-73	10-25-73	TEST PERIOD AVG.	10-29-73	10-31-73	TEST PERIOD AVG.
1.04	1.13	1.09	1.18	1.13	1.16
1.15	1.13	1.14	1.14	1.13	1.14
1.15		1.15	1.11	1.11	1.11
1.11	1.13	1.12	1.14	1.12	1.13
74.39	77.85	76.12	76.12	77.88	77.00
77.85	77.85	77.85	76.99	77.00	77.00
77.85		77.85	76.99	77.88	77.44
76.10	77.85	77.28	76.70	77.59	77.15
0.40	0.14	0.27	0.46	0.22	0.34
0.36	0.49	0.43	0.49	0.30	0.40
0.21		0.21	0.33	0.32	0.33
0.32	0.32	0.32	0.43	0.28	0.36
5.25	1.73	3.49	6.08	3.78	4.93
4.99	5.25	5.12	6.02	4.13	5.08
3.04		3.04	3.78	5.38	4.58
4.43	3.49	3.96	5.29	4.43	4.86
18.72	19.15	19.04	16.16	16.99	16.57
15.65	15.28	15.47	15.36	17.44	16.38
17.75		17.75	17.79	15.31	16.54
17.44	17.21	17.33	16.44	16.58	16.50
1.03	0.27	0.65	0.24	0.24	0.24
2.98	1.16	2.07	3.66		3.66
1.27	0.21	0.74	3.36		3.36
1.76	0.55	1.15	2.42	0.24	2.42
0.37	0.49	0.43	0.19	0.19	0.19
0.25	0.31	0.28	0.46		0.46
0.42	0.23	0.33	0.38		0.38
0.35	0.34	0.35	0.34	0.19	0.34
58.4	12.8	35.6	69.9	58.6	64.3
46.4	66.6	56.5	58.9	50.0	54.5
49.7	16.9	33.3	38.0	40.9	39.5
51.5	32.1	41.8	55.6	49.8	52.7

Table 8. SINTER BREAKER APEA GAS COMPOSITION DATA

DESCRIPTION	1ST WEEK TESTING			
	10-16-73	10-17-73	10-18-73	TEST PERIOD AVG.
HYDROGEN - % BY VOLUME				
Test 1	1.10	1.05	0.61	0.92
Test 2	1.12	1.17	1.09	1.13
Test 3	1.12		1.15	1.14
Average	1.11	1.11	0.95	1.06
NITROGEN - % BY VOLUME				
Test 1	78.49	78.49	79.33	78.77
Test 2	78.49	80.16	78.72	79.12
Test 3	78.49		78.72	78.61
Average	78.49	79.33	78.92	78.91
CARBON MONOXIDE - % BY VOLUME				
Test 1	0.01	0.03	0.02	0.02
Test 2	0.01	0.01	0.01	0.01
Test 3	0.01		0.01	0.01
Average	0.01	0.02	0.01	0.01
CARBON DIOXIDE - % BY VOLUME				
Test 1	0.13	0.12	0.25	0.17
Test 2	0.11	0.19	0.15	0.15
Test 3	0.15		0.23	0.19
Average	0.13	0.16	0.21	0.17
OXYGEN - % BY VOLUME (BY DIFF)				
Test 1	20.27	20.31	19.79	20.12
Test 2	20.27	18.47	20.03	19.59
Test 3	20.23		19.89	20.05
Average	20.26	19.38	19.91	19.85
SULFUR TRIOXIDE - PPM BASIS				
Test 1	0.10	0.71	0.19	0.33
Test 2			0.35	0.35
Test 3			0.17	0.17
Average	0.10	0.71	0.24	0.28
SULFUR DIOXIDE - PPM BASIS				
Test 1	0.23	0.26	0.30	0.26
Test 2			0.30	0.30
Test 3			0.41	0.41
Average	0.23	0.26	0.34	0.32
OXIDES OF NITROGEN - PPM AS NO_2				
Test 1	6.4	2.6	4.0	4.3
Test 2			4.0	4.0
Test 3				
Average	6.4	2.6	4.0	4.2

Table 8. (continued)

2ND WEEK TESTING			3RD WEEK TESTING		
10-22-73	10-25-73	TEST PERIOD AVG.	10-29-73	10-31-73	TEST PERIOD AVG.
1.11	1.13	1.12	1.18	1.13	1.16
1.15	1.13	1.14	1.11	1.13	1.12
1.15		1.15	1.11	1.13	1.12
1.14	1.13	1.14	1.13	1.13	1.13
77.85	76.99	77.42	77.85	78.76	78.31
77.85	77.85	77.85	76.99	78.76	77.88
77.85		77.85	77.85	78.76	78.31
77.85	77.42	77.64	77.56	78.76	78.16
0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.27	0.01	0.14
0.01		0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.10	0.01	0.06
0.14	0.17	0.16	0.22	0.05	0.14
0.16	0.08	0.12	0.12	0.14	0.13
0.14		0.14	0.21	0.12	0.17
0.15	0.13	0.14	0.18	0.10	0.14
20.89	21.70	21.29	20.74	20.05	20.38
20.83	20.93	20.88	21.51	19.96	20.73
20.85		20.85	20.82	19.98	20.39
20.85	21.31	21.07	21.03	20.00	20.51
0.22	0.33	0.28	0.14	0.19	0.17
0.29		0.29	0.14	0.16	0.15
0.24		0.24	0.35		0.35
0.25	0.33	0.27	0.21	0.18	0.22
0.25	0.52	0.39	0.20	0.39	0.30
0.25		0.25	0.19	0.29	0.24
0.28		0.28	0.29		0.29
0.26	0.52	0.31	0.23	0.34	0.28
4.9	1.3	3.1	4.0	1.0	2.5
6.9	2.6	4.8	2.6	1.0	1.8
3.7		3.7	4.0	2.0	3.0
5.2	2.0	3.9	3.5	1.3	2.4

Table 9. HOT SCREENS AREA GAS COMPOSITION DATA

DESCRIPTION	1ST WEEK TESTING			
	10-16-73	10-17-73	10-18-73	TEST PERIOD AVG.
HYDROGEN - % BY VOLUME				
Test 1	1.10	1.00	1.23	1.11
Test 2	1.12	1.11	1.09	1.11
Test 3	1.15		1.12	1.14
Average	1.12	1.06	1.15	1.12
NITROGEN - % BY VOLUME				
Test 1	78.49	78.49	78.49	78.49
Test 2	78.49	79.33	78.72	78.85
Test 3	78.49		78.72	78.61
Average	78.49	78.91	78.64	78.65
CARBON MONOXIDE - % BY VOLUME				
Test 1	0.01	0.01	0.01	0.01
Test 2	0.04	0.02	0.01	0.02
Test 3	0.01		0.02	0.02
Average	0.02	0.02	0.01	0.02
CARBON DIOXIDE - % BY VOLUME				
Test 1	0.23	0.34	0.20	0.26
Test 2	0.18	0.27	0.17	0.21
Test 3	0.32		0.32	0.32
Average	0.24	0.31	0.23	0.26
OXYGEN - % BY VOLUME (BY DIFF)				
Test 1	20.17	20.16	20.07	20.13
Test 2	20.17	19.27	20.01	19.81
Test 3	20.03		19.82	19.91
Average	20.13	19.70	19.97	19.95
SULFUR TRIOXIDE - PPM BASIS				
Test 1	0.80	1.07	0.24	0.70
Test 2				
Test 3				
Average	0.80	1.07	0.24	0.70
SULFUR DIOXIDE - PPM BASIS				
Test 1	0.37	0.30	0.68	0.45
Test 2				
Test 3				
Average	0.37	0.30	0.68	0.45
OXIDES OF NITROGEN - PPM AS NO_2				
Test 1	1.3	5.8	5.3	4.1
Test 2				
Test 3				
Average	1.3	5.8	5.3	4.1

Table 9. (continued)

2ND WEEK TESTING			3RD WEEK TESTING		
10-22-73	10-25-73	TEST PERIOD AVG.	10-29-73	10-31-73	TEST PERIOD AVG.
1.14	1.13	1.14	1.18	1.16	1.17
1.14	1.16	1.15	1.14	1.18	1.16
1.15		1.15	1.11	1.13	1.12
1.14	1.15	1.15	1.14	1.16	1.15
77.85	77.85	77.85	78.72	78.76	78.74
78.72	77.85	78.29	77.85	78.76	78.31
77.85		77.85	77.85	78.76	78.31
78.14	77.85	78.00	78.14	78.76	78.45
0.01	0.01	0.01	0.01	0.03	0.02
0.01	0.01	0.01	0.02	0.02	0.02
0.01		0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.02	0.02	0.02
0.42	0.30	0.36	0.19	0.46	0.33
0.05	0.11	0.08	0.39	0.52	0.46
0.09		0.09	0.29	0.11	0.20
0.19	0.21	0.18	0.29	0.36	0.33
20.58	20.71	20.64	19.90	19.59	19.74
20.08	20.87	20.47	20.60	19.52	20.05
20.90		20.90	20.74	19.99	20.36
20.52	20.78	20.66	20.41	19.70	20.05
0.46	0.15	0.31	0.20	0.34	0.27
0.39		0.39	0.51		0.51
0.94		0.94	0.22		0.22
0.60	0.15	0.55	0.31	0.34	0.33
1.08	0.33	0.71	0.20	0.32	0.26
0.64		0.64	0.52		0.52
0.81		0.81	0.32		0.32
0.84	0.33	0.72	0.35	0.32	0.37
8.4	8.3	8.4	6.5	5.1	5.8
5.1	2.2	3.7	4.3	2.4	3.4
7.9	5.3	6.6	5.8	1.2	3.5
7.1	5.3	6.2	5.5	2.9	4.2

The data for the hot screens area generally indicates an increase in particulate and inorganic condensables and a decrease in organic condensables with increasing basicity.

Particulate in the sinter breaker and hot screens discharge gases is so substantial that these gases should not be considered for oxygen enrichment unless more effective gas cleaning is achieved. Sinter production upsets could cause the recycled gas to become pressurized in the hood over the sinter machine and discharge dirty gases into the plant atmosphere.

Table 11 shows the analysis of the emissions collected in the field sampling trains. The data indicates a definite increase in the calcium, magnesium, and carbonate content of the dust from all three sampling areas, as the sinter product basicity increases. The iron in the dust, on the other hand, decreased. These analytical evaluations are consistent with the type of sinter being produced.

Tables 12 and 13 summarize the previous seven tables. In addition, gas flowrates are presented for future use in the development of a gas recirculation system.

Table 10. EMISSIONS DATA

DESCRIPTION	1ST WEEK TESTING: 10-16-73	10-17-73	10-18-73	AVERAGE
MAIN EXHAUST STACK				
Particulate mg/m³ (gr/scf)	44.3 (0.019)	159.8 (0.061)	179.1 (0.078)	121.1 (0.053)
Inorganic condensables mg/m³ (gr/scf)	23.1 (0.010)	1.7 (0.0007)	131.2 (0.057)	52.0 (0.022)
Organic condensables mg/m³ (gr/scf)	18.9 (0.008)	0.4 (0.0002)	6.2 (0.003)	8.5 (0.004)
SINTER BREAKER AREA				
Particulate mg/m³ (gr/scf)	164.7 (0.072)	74.6 (0.032)	159.0 (0.069)	132.8 (0.058)
Inorganic condensables mg/m³ (gr/scf)	53.8 (0.023)	11.1 (0.005)	39.0 (0.017)	34.6 (0.015)
Organic condensables mg/m³ (gr/scf)	38.6 (0.017)	1.6 (0.001)	5.8 (0.003)	15.3 (0.007)
6th SCREEN AREA				
Particulate mg/m³ (gr/scf)	124.1 (0.054)	76.5 (0.033)	214.4 (0.093)	138.3 (0.060)
Inorganic condensables mg/m³ (gr/scf)	57.3 (0.025)	16.4 (0.007)	134.1 (0.058)	69.4 (0.030)
Organic condensables mg/m³ (gr/scf)	11.0 (0.005)	0.3 (0.0002)	14.6 (0.006)	8.7 (0.004)

mg/m³ = milligrams of particulate per cubic meter of gas at 21.1°C (70°F) and 1.0 atmosphere pressure

Table 10. (continued)

2ND WEEK TESTING			3RD WEEK TESTING		
10-22-73	10-25-73	AVERAGE	10-29-73	10-31-73	AVERAGE
165.4 (0.072)	159.0 (0.069)	162.2 (0.071)	155.7 (0.068)	204.0 (0.089)	179.9 (0.078)
67.3 (0.029)	100.2 (0.043)	83.8 (0.036)	62.8 (0.027)	213.3 (0.093)	138.0 (0.060)
8.7 (0.004)	9.6 (0.004)	9.1 (0.004)	4.4 (0.002)	7.2 (0.003)	5.8 (0.003)
67.3 (0.029)	150.6 (0.066)	109.0 (0.048)	109.2 (0.048)	52.0 (0.023)	80.6 (0.035)
46.5 (0.020)	67.7 (0.029)	57.1 (0.025)	21.1 (0.009)	64.4 (0.028)	42.8 (0.018)
5.7 (0.002)	7.4 (0.003)	6.5 (0.003)	1.9 (0.001)	2.6 (0.001)	2.2 (0.001)
251.1 (0.109)	80.9 (0.035)	166.0 (0.072)	2178.5 (0.952)	1083.7 (0.473)	1631.1 (0.713)
100.9 (0.044)	8.25 (0.004)	91.7 (0.040)	90.9 (0.039)	519.0 (0.227)	305.0 (0.133)
6.3 (0.003)	7.9 (0.003)	7.1 (0.003)	1.5 (0.001)	2.7 (0.001)	2.1 (0.001)

Table 11. EMISSIONS CHEMICAL COMPOSITION

DESCRIPTION	1ST WEEK TESTING			
	10-16-73	10-17-73	10-18-73	TEST PERIOD AVERAGE
MAIN EXHAUST STACK				
Wt. % - Fe (a)		13.6	17.9	15.9
Wt. % - Ca		8.6	11.9	10.2
Wt. % - Mg		2.0	1.6	1.8
Wt. % - CO_3		4.1	7.2	5.7
Wt. % - Organic (b)		1.9	3.2	2.6
Wt. % - Combustible (c)		15.8	13.4	14.6
Wt. % - Undetermined (d)		54.0	44.8	49.4
SINTER BREAKER AREA				
Wt. % - Fe	8.4	24.7	21.9	18.3
Wt. % - Ca	4.3	12.3	13.0	9.9
Wt. % - Mg	1.3	3.4	3.2	2.6
Wt. % - CO_3	1.1	4.0	9.2	4.8
Wt. % - Organic	0.1	0.3	2.6	1.0
Wt. % - Combustible	2.5	7.4	9.8	6.6
Wt. % - Undetermined	82.3	47.9	40.3	56.8
HOT SCREENS AREA				
Wt. % - Fe	24.5	21.0	25.6	23.6
Wt. % - Ca	11.8	11.5	9.6	10.9
Wt. % - Mg	2.9	2.8	2.3	2.7
Wt. % - CO_3	4.2	7.5	12.5	8.1
Wt. % - Organic	1.4	1.2	2.1	1.6
Wt. % - Combustible	8.2	7.7	8.0	8.0
Wt. % - Undetermined	47.0	48.3	39.9	45.1

(a) Values presented are average values of samples taken in any sampling day.
(b) Represents material that was soluble in petroleum ether.
(c) Represents material lost from sample at 450°C.
(d) Value of difference between given chemical composition and 100%.

Table 11. (continued)

2ND WEEK TESTING			3RD WEEK TESTING		
10-22-73	10-25-73	TEST PERIOD AVERAGE	10-29-73	10-31-73	TEST PERIOD AVERAGE
14.0	13.0	13.5	9.5	14.0	11.8
13.6	10.4	12.0	11.8	16.2	14.0
4.1	2.2	3.2	5.0	6.2	5.6
11.3	2.1	6.1	6.1	14.5	10.3
2.3	5.4	3.8	3.6	1.9	2.7
13.2	14.1	13.7	14.1	14.9	14.5
41.5	52.8	47.1	49.9	32.3	41.1
24.1	18.2	21.2	19.8	22.1	20.9
18.4	11.2	14.8	18.2	16.0	17.1
6.4	2.7	4.6	7.8	7.1	7.5
7.7	5.3	6.5	7.4	6.7	7.1
4.2	4.9	4.5	1.2	3.7	2.4
12.1	11.3	11.7	9.2	12.0	10.6
27.1	46.4	36.7	36.4	32.4	34.4
19.5	19.2	19.3	17.0	19.2	18.1
13.4	14.5	14.0	7.2	9.7	8.4
5.0	2.2	3.6	3.0	4.2	3.6
9.8	8.8	9.3	18.6	20.6	19.6
1.8	6.6	4.2	0.1	0.4	0.3
10.5	10.7	10.6	6.3	6.5	6.4
40.0	38.0	39.0	47.8	39.4	43.6

Table 12. FIELD TEST SUMMARY

DESCRIPTION	PLANT PRODUCTION mtpd (tpd)	PRODUCT BASICITY	GAS FLOWRATE m^3/s (acfm)	GAS TEMPERATURE C° (F°)
MAIN EXHAUST STACK			335.6 (a) (710,955)	43 (a) (110)
1st week testing (b)	5201 (5730)	2.05		79 (174)
2nd week testing (b)	4729 (5210)	2.35		81 (178)
3rd week testing (b)	3768 (4149)	2.91		81 (178)
SINTER BREAKER AREA			29.0 (a) (61,350)	34 (a) (94)
1st week testing	5201 (5730)	2.05		35 (96)
2nd week testing	4729 (5210)	2.35		34 (93)
3rd week testing	3768 (4149)	2.91		33 (91)
HOT SCREEN AREA			53.0 (a) (113,000)	39 (a) (102)
1st week testing	5201 (5730)	2.05		54 (129)
2nd week testing	4729 (5210)	2.35		44 (111)
3rd week testing	3768 (4149)	2.91		32 (89)

(a) Actual gas flowrates and related temperatures were determined immediately preceding actual field test periods.
(b) Related values in table presented as weekly averages.

Table 12. (continued)

GAS COMPOSITION							
H_2 %	N_2 %	CO %	CO_2 %	O_2 %	SO_3 PPM	SO_2 PPM	NO_X PPM
1.07	78.16	0.48	5.11	15.18	6.23	0.44	43.6
1.12	77.28	0.32	3.96	17.33	1.15	0.35	41.8
1.13	77.15	0.36	4.86	16.50	2.42	0.34	52.7
1.06	78.91	0.01	0.17	19.85	0.28	0.32	4.2
1.14	77.64	0.01	0.14	21.07	0.27	0.31	3.9
1.13	78.16	0.06	0.14	20.51	0.22	0.28	2.4
1.12	78.65	0.02	0.26	19.95	0.70	0.45	4.1
1.15	78.00	0.01	0.18	20.66	0.55	0.72	6.2
1.15	78.45	0.02	0.33	20.05	0.33	0.37	4.2

Table 13. FIELD TEST SUMMARY

DESCRIPTION	PARTICULATE mg/m^3 (gr/scf)	INORGANIC CONDENSABLES mg/m^3 (gr/scf)	ORGANIC CONDENSABLES mg/m^3 (gr/scf)
MAIN EXHAUST STACK			
1st week testing	121.1 (0.053)	52.0 (0.023)	8.5 (0.004)
2nd week testing	162.2 (0.071)	83.8 (0.036)	9.1 (0.004)
3rd week testing	179.9 (0.078)	138.0 (0.060)	5.8 (0.003)
SINTER BREAKER AREA			
1st week testing	132.8 (0.058)	34.6 (0.015)	15.3 (0.007)
2nd week testing	109.0 (0.047)	57.1 (0.025)	6.5 (0.003)
3rd week testing	80.6 (0.035)	42.8 (0.018)	2.2 (0.001)
HOT SCREEN AREA			
1st week testing	138.3 (0.060)	69.4 (0.030)	8.7 (0.004)
2nd week testing	166.0 (0.072)	91.7 (0.040)	7.1 (0.003)
3rd week testing	1631.1 (0.713)	305.0 (0.133)	2.1 (0.001)

SECTION VI
PROCESS DESIGN

PROCESS DESIGN STUDY

Introduction

Contained herein is the design study for a Waste Gas Recycle System on No. 2 Sinter Strand for Weirton Steel Division, National Steel Corporation, Weirton, West Virginia. The system offers the following potential advantages:

Reduces the quantity of gases to be cleaned.

Reduces the capital investment for final gas cleaning equipment.

Reduces the total emission to the atmosphere for a given dust concentration.

Reduces the hydrocarbon content in exhaust gases.

Increases flexibility of operation.

These potential advantages justified the design of a waste gas recirculation system.

Design Considerations

Synthesis of the waste gas recycle system required the evaluation of two limiting parameters. These parameters were (1) the gas oxygen content which affects the combustion process and sinter quality, and (2) the minimizing of downtime during the retrofit of the Sinter Plant so that sinter would always be available to the blast furnaces. Figure 1 in Section III shows the general arrangement of the recirculation system installed at the Weirton Steel Division No. 2 Sinter Strand. Table 14 is a summary of the waste gas process calculations for this system as a function of recycle percentage. Based on these results, it was concluded that a 39% recycle should be the maximum design recirculation rate because of the rapidly decreasing oxygen content in the recirculated gas and the large rate of increase in fan horsepower with increasing recycle percentage.

System Description

Two waste gas fans, identical in performance and construction, operate in parallel. They are sized to discharge to the main exhaust stack all the waste gas from the sintering strand or to recirculate to the sintering machine hood up to 39% of the waste gas. Four duct valves, two for flow control and two for shutoff, control the waste gas recirculated to the sinter machine. The control system permits a once through operation or recirculation rates ranging from 0 to 50%. Provision is made for additional cleaning of the unrecirculated waste gas prior to discharge to the atmosphere. Specifications used as the basis for equipment selection are as follows:

Once Through Operation - each fan:

Standard gas flow	88.0 Nm^3/s	(200,000 scfm)
Actual gas flow	159.8 m^3/s	(340,000 acfm)
Temperature	139°C	(282°F)
Density	0.743 kg/m^3	(0.0464 lbs/cf)
Fan static pressure	1118 mm wc	(44.0 in)
Fan motor power	2615 kw	(3505 bhp)

39% Waste Gas Recycle to Machine Hood - each fan:

Standard gas flow	88.0 Nm^3/s	(200,000 scfm)
Actual gas flow	184.7 m^3/s	(393,000 acfm)
Temperature	194°C	(382°F)
Density	0.646 kg/m^3	(0.0403 lbs/cf)
Fan static pressure	1290 mm wc	(50.8 in)
Fan motor power	3328 kw	(4327 bhp)

Recycle Hood -

Standard volume	68.6 Nm^3/s	(156,000 scfm)
Actual volume	136.3 m^3/s	(290,000 acfm)
Temperature	219°C	(427°F)
Oxygen	17.56% above sinter bed	

Future Gas Cleaning System - inlet conditions:

Standard volume	107.4 Nm^3/s	(244,000 scfm)
Actual volume	212.9 m^3/s	(453,000 acfm)
Temperature	219°C	(427°F)
Pressure	51 mm wc positive	(2 in)
Moisture	74.42 g/Nm^3	(30.25 grains/scf)
Dust	0.923 g/Nm^3	(0.375 grains/scf)
Hydrocarbons	0.369 g/Nm^3	(0.150 grains/scf)

Table 14. SUMMARY OF CALCULATED DATA*

% of Waste Gas Recycled		0	10
Gas flow each fan (dry)	Nm^3/s (scfm)	88.0 (200,000)	88.0 (200,000)
Waste gas temperature at fan	°C (°F)	139 (282)	150 (302)
Pressure drop across 356 mm (14 in) sinter bed	mm wc (in wc)	762 (30)	785 (30.9)
Pressure drop in existing cyclones	mm wc (in wc)	203 (8.0)	208 (8.2)
Pressure drop in ductwork to fan	mm wc (in wc)	102 (4.0)	109 (4.3)
Fan inlet pressure	mm wc (in wc)	-1067 (-42.0)	-1102 (-43.4)
Gas volume at fan inlet	m^3/s (acfm)	159.8 (340,000)	165.4 (352,000)
Gas density	kg/m^3 (lbs/cu ft)	0.743 (0.0464)	0.721 (0.0450)
Pressure drop in fan ductwork to hood	mm wc (in wc)	50.8 (2.0)	53.3 (2.1)
Fan static pressure	mm wc (in wc)	1118 (44.0)	1156 (45.5)
Fan motor power	kw (bhp)	2615 (3505)	2745 (3680)
Volume recycled (dry)	Nm^3/s (scfm)	0 (0)	17.6 (40,000)
Volume recycled to hood	m^3/s (acfm)	0 (0)	31.0 (66,000)
Oxygen above sinter bed	%	21.00	20.35
Gas flow to stack	m^3/s (acfm)	284.4 (605,000)	279.7 (595,000)
Saturated gas flow to stack	m^3/s (acfm)	236.9 (504,000)	216.2 (460,000)
Saturation gas temperature	°C (°F)	50 (122)	52 (125)

* see Appendix B for calculations used to compile this table.

Table 14. (continued)

20	30	39	50
88.0 (200,000)	88.0 (200,000)	88.0 (200,000)	88.0 (200,000)
163 (325)	178 (352)	194 (382)	226 (438)
800 (31.5)	818 (32.2)	856 (33.7)	927 (36.5)
213 (8.4)	224 (8.8)	229 (9.0)	246 (9.7)
117 (4.6)	127 (5.0)	135 (5.3)	145 (5.7)
-1130 (-44.5)	-1168 (-46.0)	-1219 (-48.0)	-1318 (-51.9)
171.6 (365,000)	178.6 (380,000)	184.7 (393,000)	205.4 (437,000)
0.697 (0.0435)	0.674 (0.0421)	0.646 (0.0403)	0.593 (0.0370)
58.4 (2.3)	63.5 (2.5)	71.1 (2.8)	81.3 (3.2)
1189 (46.8)	1232 (48.5)	1290 (50.8)	1400 (55.1)
2880 (3880)	3051 (4090)	3228 (4327)	3849 (5160)
35.2 (80,000)	52.8 (120,000)	68.6 (156,000)	88.0 (200,000)
63.9 (136,000)	99.6 (212,000)	136.88 (290,000)	189.4 (403,000)
19.66	18.70	17.56	1[illegible]5
256.2 (545,000)	233.6 (497,000)	212.9 (453,000)	189.4 (403,000)
194.6 (414,000)	173.4 (369,000)	155.1 (330,000)	133.0 (283,000)
53 (127)	55 (131)	57 (134)	60 (140)

System Features - This waste gas recycle system offers the following advantageous features:

System can be retrofitted to the sinter plant as a peripheral facility with minimum downtime for a final tie-in.

Highest ratio of recirculation of waste gases to machine hood while maintaining an adequate amount of oxygen for the sintering process.

Conservation of energy required for sintering process by recirculating hot gases.

Flexibility of operation in handling sintering machine waste gases.

Flexibility for meeting existing or future air pollution regulations.

Smaller inventory of spare parts needed because both waste gas fans and drives are identical.

Low initial capital investment.

Discussion - Fan selection for this system has been based on maximum wind flow volumes, temperatures and pressures as determined from test data.

For this report, total process wind volume is defined as 187.44 Nm^3/s (426,000 scfm), containing 49.2 g/Nm^3 (20 grains per scf) of moisture or 176.0 Nm^3/s (400,000 scfm) of dry gas.

Table 14 shows calculated waste gas fan and future gas cleaning data for 0 to 50% recirculation.

Appendix B contains the process design calculations used in the design of the gas recirculation system.

Future Discharge Waste Gas Cleaning System

Several types of future gas cleaning systems have been considered for the treatment before discharge to atmosphere of 61% of waste gas.

Three of the most promising systems are wet scrubbers, wet electrostatic precipitators, and gravel bed filters.

Wet Scrubber - A wet scrubber system would require an additional fan operating in series with the waste gas fan, wet scrubber and moisture eliminator. This system would also require scrubber water recirculating pumps, pumps to transfer slurry to an existing thickener, a water treatment system, and controls.

Scrubber fan -

Standard gas flow	107.4 Nm^3/s	(244,000 scfm)
Actual gas flow	212.9 m^3/s	(453,000 acfm)
Gas temperature	219°C	(427°F)
Gas density	0.716 kg/m^3	(0.0447 lbs/cf)
Fan static pressure	1143 mm wc	(45 in)
Fan motor power	3320 kw	(4450 bhp)

Scrubber inlet conditions -

Gas flow	202.1 m^3/s	(430,000 acfm)
Pressure	1194 mm positive	(47 in)
Temperature	241°C	(465°F)
Moisture	74.42 g/Nm^3	(30.25 grains/scf)
Dust	0.923 g/Nm^3	(0.375 grains/scf)
Hydrocarbons	0.369 g/Nm^3	(0.150 grains/scf)

Scrubber outlet conditions -

Gas flow	157.5 m^3/s saturated	(335,000 acfm)
Pressure	51 mm wc positive	(2 in)
Temperature	58°C saturated	(136°F)
Dust and hydrocarbons	0.049 g/Nm^3	(0.02 grains/scf)
Water evaporated	65.4 m^3/h	(288 gpm)

Moisture eliminator - Electrostatic type, expected to be highly efficient in reducing the rain-out problem.

Water recirculating pumps -

Flow	681 m^3/h	(3000 gpm)
Total dynamic head	22.9 m	(75 ft)
Motor power	75 kw	(100 bhp)

Slurry transfer (blow-down) pumps -

Flow	136.2 m^3/h	(600 gpm)
Total dynamic head	22.9 m	(75 ft)
Motor power	15 kw	(20 bhp)

Slurry load to thickener -

Flow	136.2 m^3/h	(600 gpm)
Solids	8.6 mtpd	(9.5 short tons/day)

Advantages of wet scrubber -

Relatively low initial capital investment.

Low maintenance cost.

Proven in sintering plant applications.

Disadvantages of wet scrubber -

Requires gas pressure booster fan.

Low hydrocarbon removal efficiency.

High power consumption.

Limitation in size which could require two scrubber-separator sets to handle gas flow.

Requires expensive recirculating water and blow-down water treatment systems.

Wet Electrostatic Precipitator -

Precipitator inlet conditions -

Standard gas flow	107.4 Nm^3/s	(244000 scfm)
Actual gas flow	212.9 m^3/s	(453000 acfm)
Pressure	51 mm wc	(2 in)
Temperature	219°C	(427°F)
Moisture	74.42 g/Nm^3	(30.25 grains/scf)
Dust	0.923 g/Nm^3	(0.375 grains/scf)
Hydrocarbons	0.369 g/Nm^3	(0.150 grains/scf)

Precipitator outlet conditions -

Actual gas flow	156.0 m^3/s	(332000 acfm)
Pressure	13 mm wc positive	(0.5 in)
Temperature	57°C	(134.5°F)
Dust and hydrocarbons	0.049 g/Nm^3	(0.02 grains/scf)
Water evaporated	61.3 m^3/h	(270 gpm)

Moisture eliminator - Electrostatic type, expected to be highly efficient in reducing rain-out problem.

Water recirculating pumps -

Flow	351.9 m^3/h	(1550 gpm)
Total dynamic head	47.3 m	(155 ft)
Motor power	78 kw	(105 bhp)

Slurry transfer (blow-down) pumps -

Flow	136.2 m^3/h	(600 gpm)
Total dynamic head	22.9 m	(75 ft)
Motor power	15 kw	(20 bhp)

Slurry load to thickener -

Flow	136.2 m^3/h	(600 gpm)
Solids	8.6 mtpd	(9.5 short tons/day)

Advantages of wet precipitator -

Low pressure drop. A gas pressure booster fan is not required.

Low fire hazard.

High gas cleaning efficiency.

Low stack rain-out.

Disadvantages of wet precipitator -

Very high initial cost.

High real estate space requirement.

Have not been proved in actual sinter plant application.

Gravel Bed Filters -

Filter inlet conditions -

Standard gas flow	107.4 Nm^3/s	(244,000 scfm)
Actual gas flow	212.9 m^3/s	(453,000 acfm)
Pressure	51 mm wc	(2 in)
Temperature	219°C	(427°F)
Moisture	74.62 g/Nm^3	(30.25 grains/scf)
Dust	0.923 g/Nm^3	(0.375 grains/scf)
Hydrocarbons	0.369 g/Nm^3	(0.150 grains/scf)

Filter outlet conditions -

Gas flow	212.9 m^3/s	(453,000 acfm)
Pressure	203.2 mm wc negative	(-8 in)
Temperature	219°C	(427°F)
Dust and hydrocarbons	0.049 g/Nm^3	(0.02 grains/scf)

Filter fan -

Standard gas flow	107.4 Nm^3/s	(244,000 scfm)
Actual gas flow	212.9 m^3/s	(453,000 acfm)
Temperature	219°C	(427°F)
Density	0.716 kg/m^3	(0.0447 lbs/cf)
Fan static pressure	254.0 mm wc	(10 in)
Fan motor power	729 kw	(977 bhp)

Advantages of gravel bed filter -

Relatively low initial capital investment.

Low maintenance cost.

System is totally dry. No water treatment necessary.

No stack rain-out.

Disadvantage of gravel bed filter -

Gas pressure booster fan and reverse flow cleaning fan required.

High real estate space requirement.

Have not been proved in actual sinter plant application.

Equipment Selection Prior to Atmospheric Discharge - Based on pilot testing and the advantages listed above, a gravel bed filter system has been selected for full scale evaluation. This system is sized to handle approximately 50% of the waste gas from the sinter strand. Testing will be conducted for once-through and for recycle conditions.

PROCESS DESCRIPTION

This chapter describes the operation and control of the waste gas recirculation system.

Figure 7 is the air and gas flow diagram for waste gas recycle system showing some of the instrumentation used to control the fans, the hood valves and the stack valves.

Figure 8 through 11 illustrate the various components included in this new system. All have been constructed of carbon steel.

Two exhaust gas fans arranged in parallel provide the induced draft necessary for processing and dust collecting.

Exhaust gases pass through two parallel hot mains to two banks of cyclone dust collectors for removal of the larger solid particles. Each bank of collectors handles fifty percent of the total machine exhaust volume. From the cyclones, the gases flow to a plenum chamber for distribution to the induced draft fans. The waste gas fan draws fifty percent of the gas volume from the plenum chamber and exhausts it to the stack. The recycle gas fan draws fifty percent of the total exhaust gas volume from the plenum chamber, and distributes 39% of the total exhaust volume to the recycle hood over the machine and the remainder to the stack.

The design basis for this recirculation system has been established at a recycle rate of thirty-nine percent of the waste gas. However, to allow for field adjustment and flexibility of operation, the equipment can be adjusted from zero to fifty percent recirculation.

The recycle gases are returned to the machine in a common header from which six ducts distribute the gases along the length of the sinter bed.

Since the recycle gases provide only thirty-nine percent of the process air requirement, the remaining sixty-one percent is introduced to the sinter bed through adjustable openings in the recycle hood.

Control Description

Waste Gas Fan - The output of the waste gas fan, fifty percent of the total gas flow through the sinter machine, is directed to the waste gas stack.

The waste gas fan operation can be controlled either manually or automatically. The manual mode must be used for fan start-up. The automatic mode is used for normal on line operation.

In the automatic mode, fan volume is controlled by monitoring the motor load current and regulating the inlet louver dampers accordingly. The controller closes the inlet louver dampers when the motor current increases above the normal operating value.

Fan pressure and motor current are continuously recorded.

Visible and audible alarms are provided on both motor and fan bearings to annunciate abnormal temperatures and vibrations.

Recycle Gas Fan - The output of the recycle gas fan is divided between the sinter machine hood and the waste gas stack. Its operation and control is identical to that of the waste gas fan.

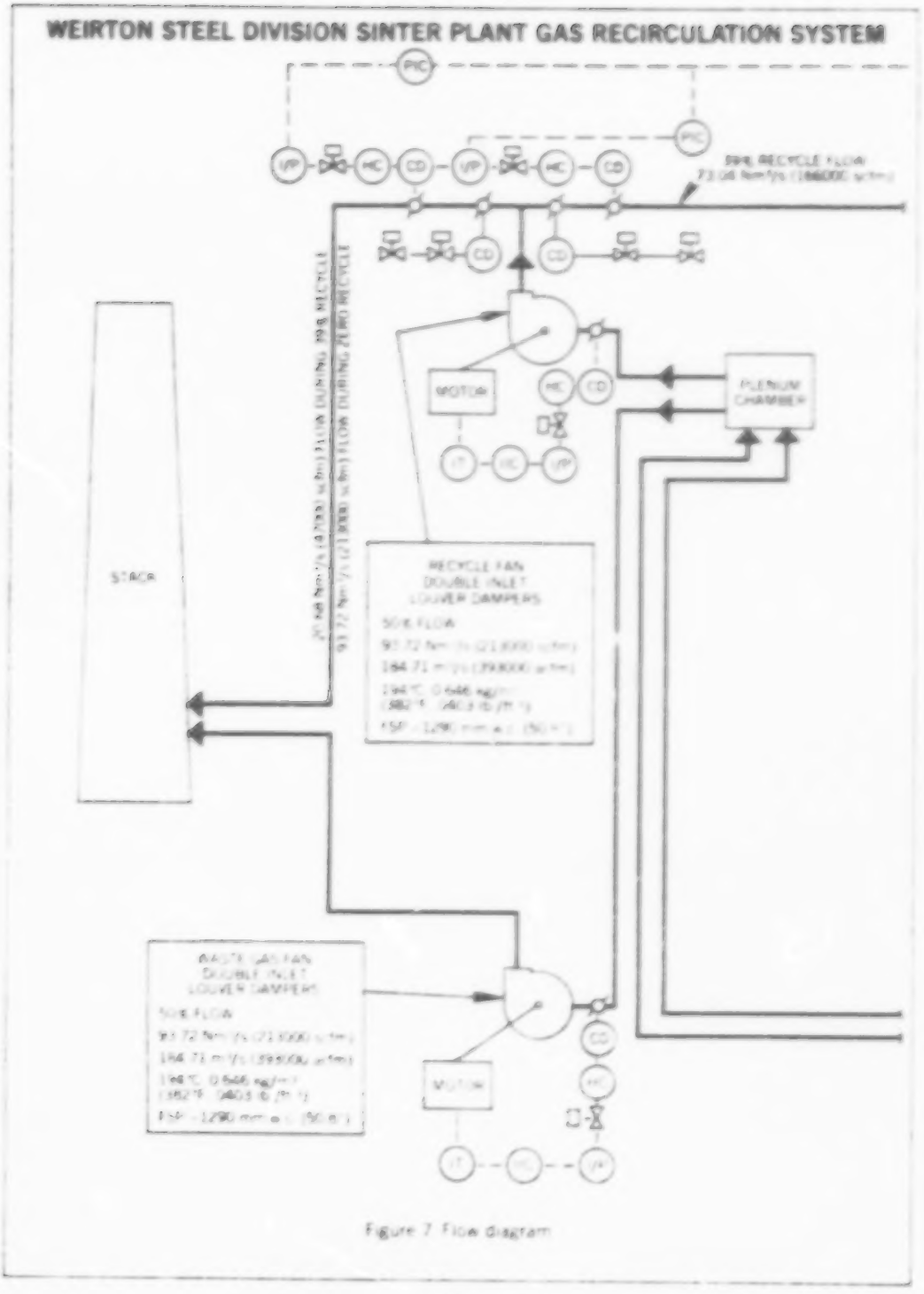

Figure 7 Flow diagram

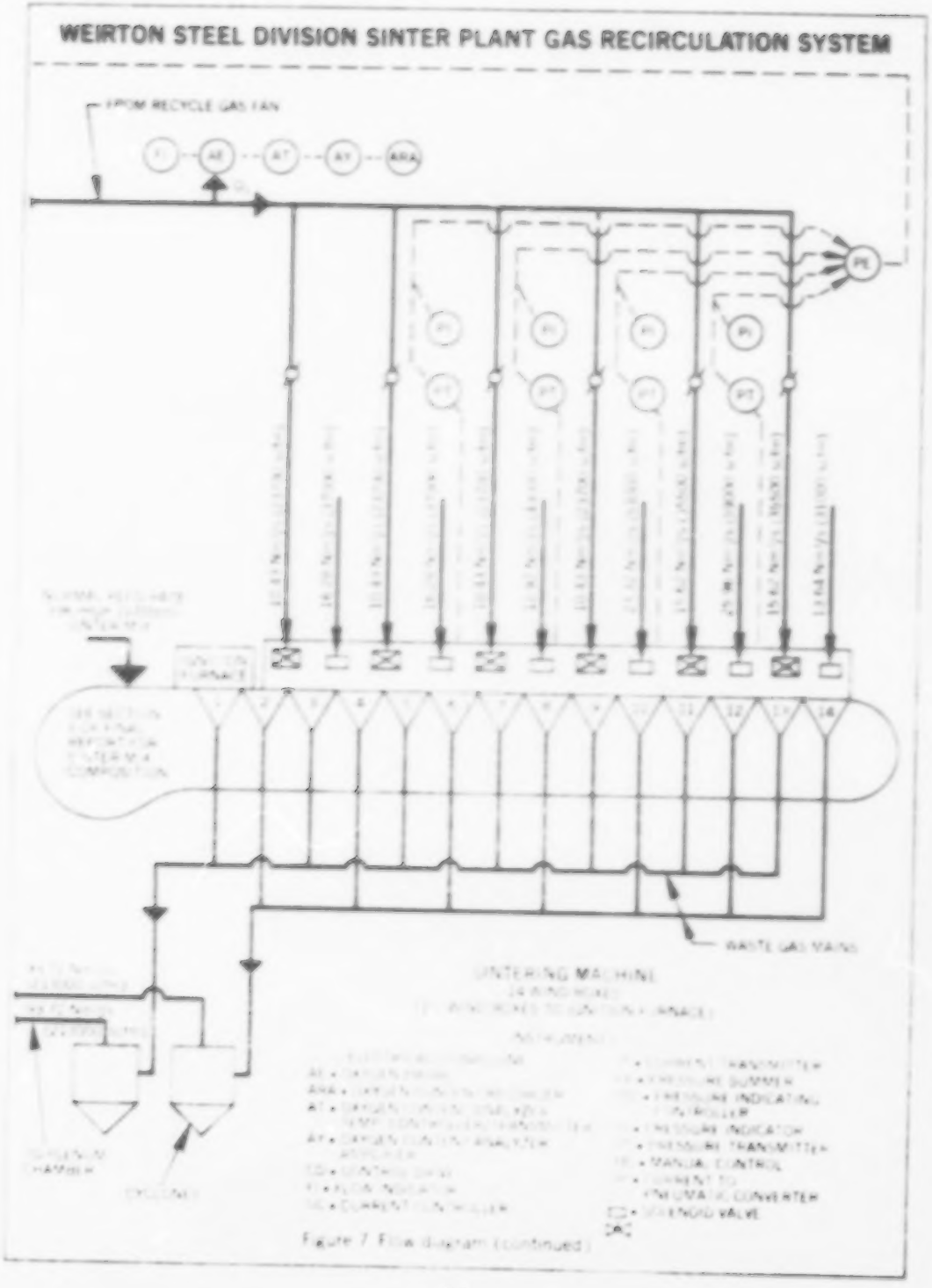

Figure 7. Flow diagram (continued)

The gas recycled to the sinter machine hood is proportioned by positioning two valves, one in the duct to the hood and the other in the duct to the stack.

Hood and Stack Valves - Hood and stack valve control circuits are so arranged that either valve can be selected to provide range control of the volume and pressure of gas recycled to the sinter machine hood while the other valve provides trim control. The selected range valve is manually positioned and the trim valve is positioned automatically to maintain the desired hood pressure. In the automatic mode the controller senses hood pressure, and positions the selected valve in the duct to control the pressure in the hood.

Two similar valves, one each upstream of the hood and stack valves, are normally used for shut-off. They are operated manually.

The hood pressure and the oxygen content of the recycle gas are continuously recorded.

Visible and audible alarms are provided for annunciating out-of-limits hood pressure and oxygen content.

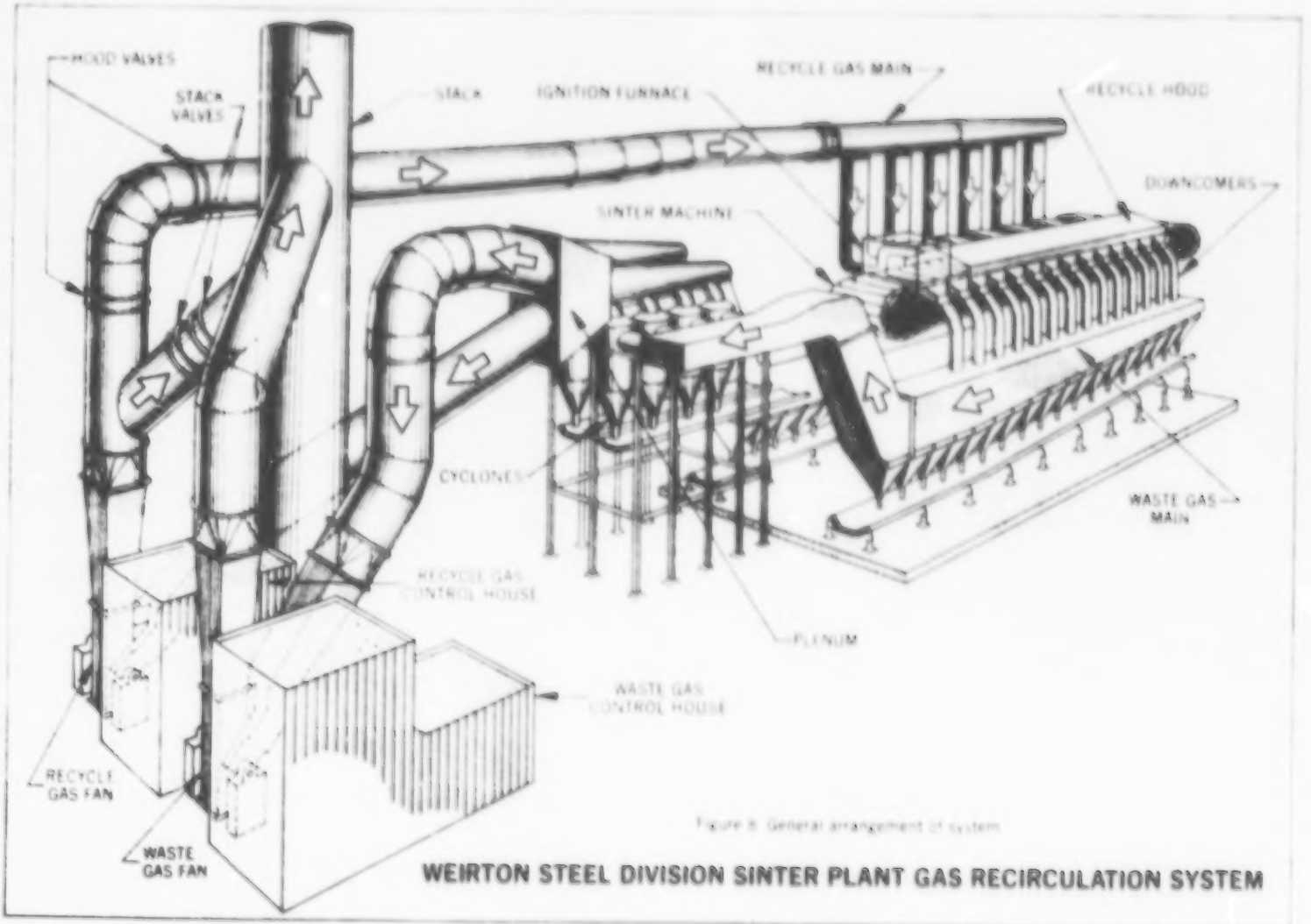

Figure 8. General arrangement of system

WEIRTON STEEL DIVISION SINTER PLANT GAS RECIRCULATION SYSTEM

WEIRTON STEEL DIVISION SINTER PLANT GAS RECIRCULATION SYSTEM

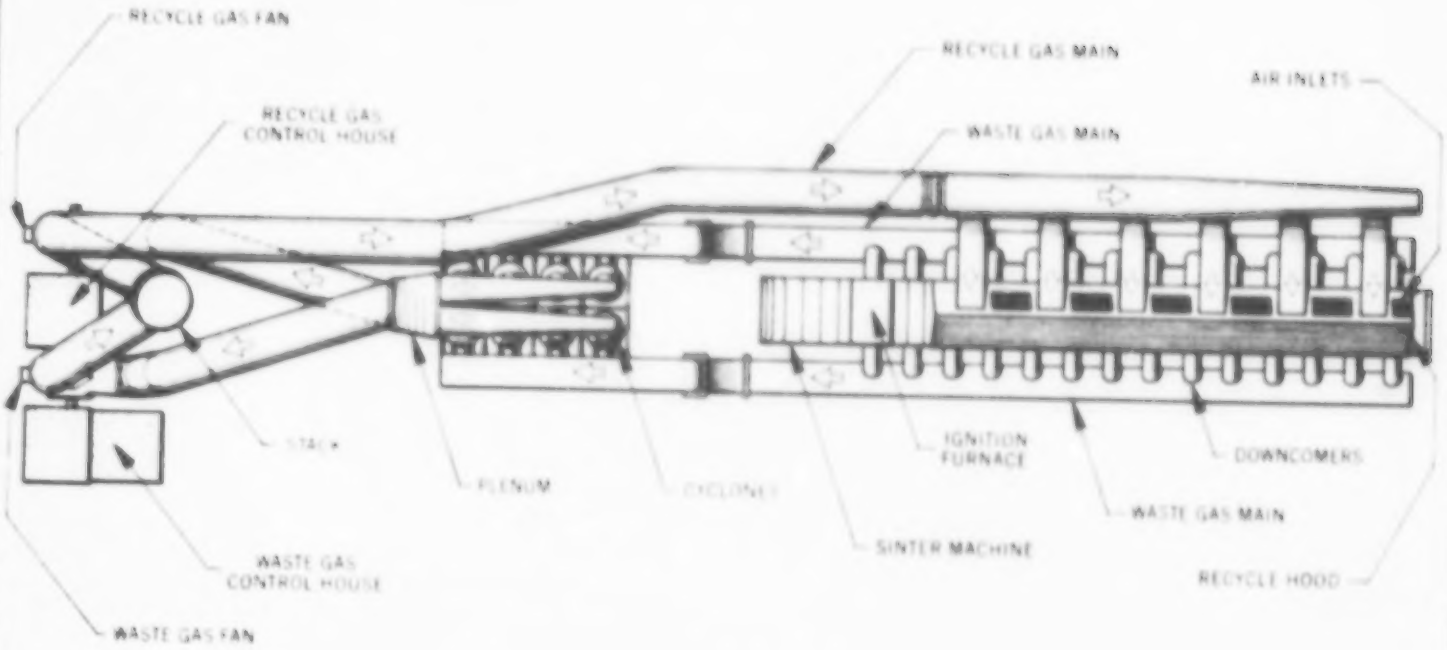

Figure 4 Plan

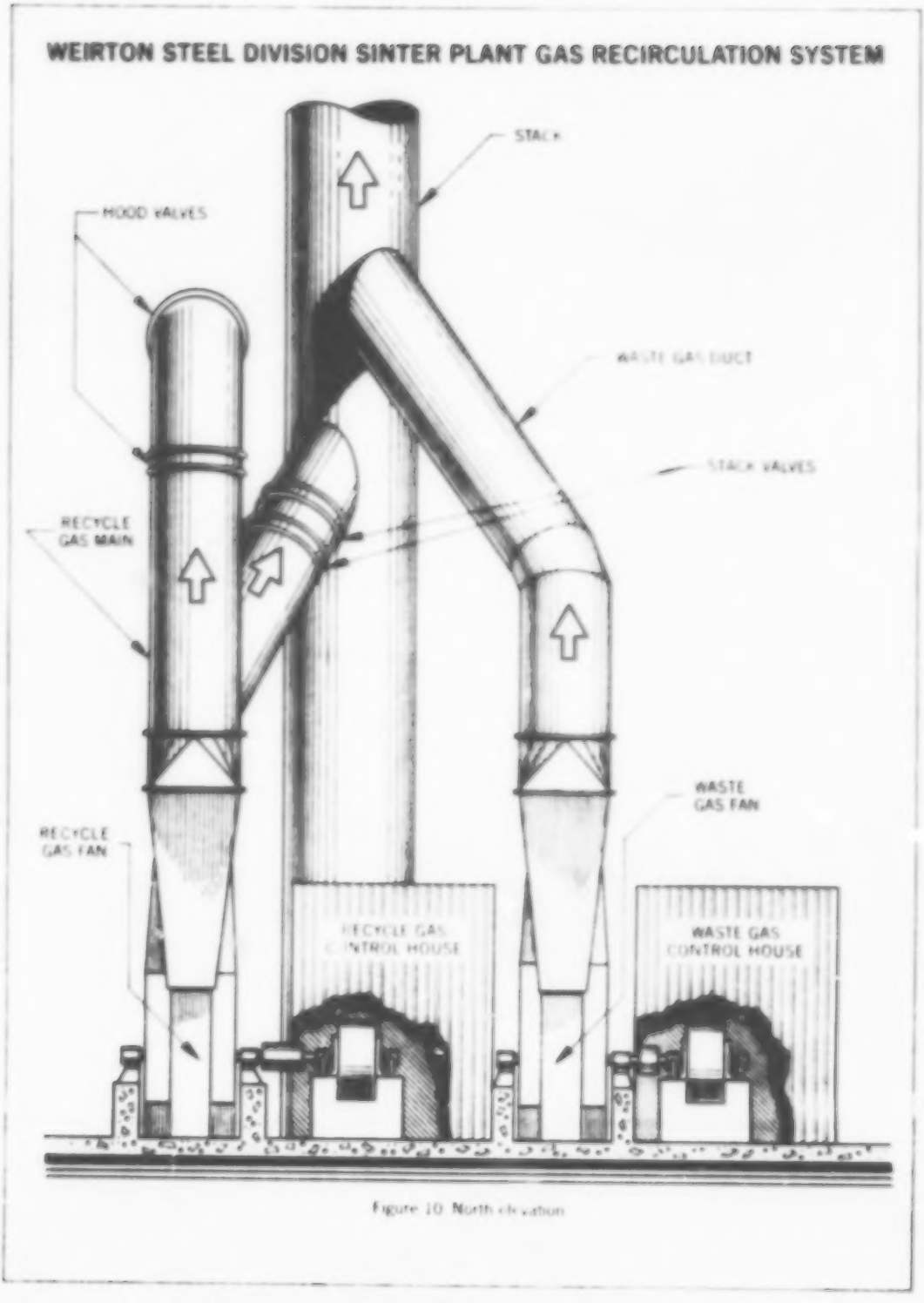

Figure 10. North elevation

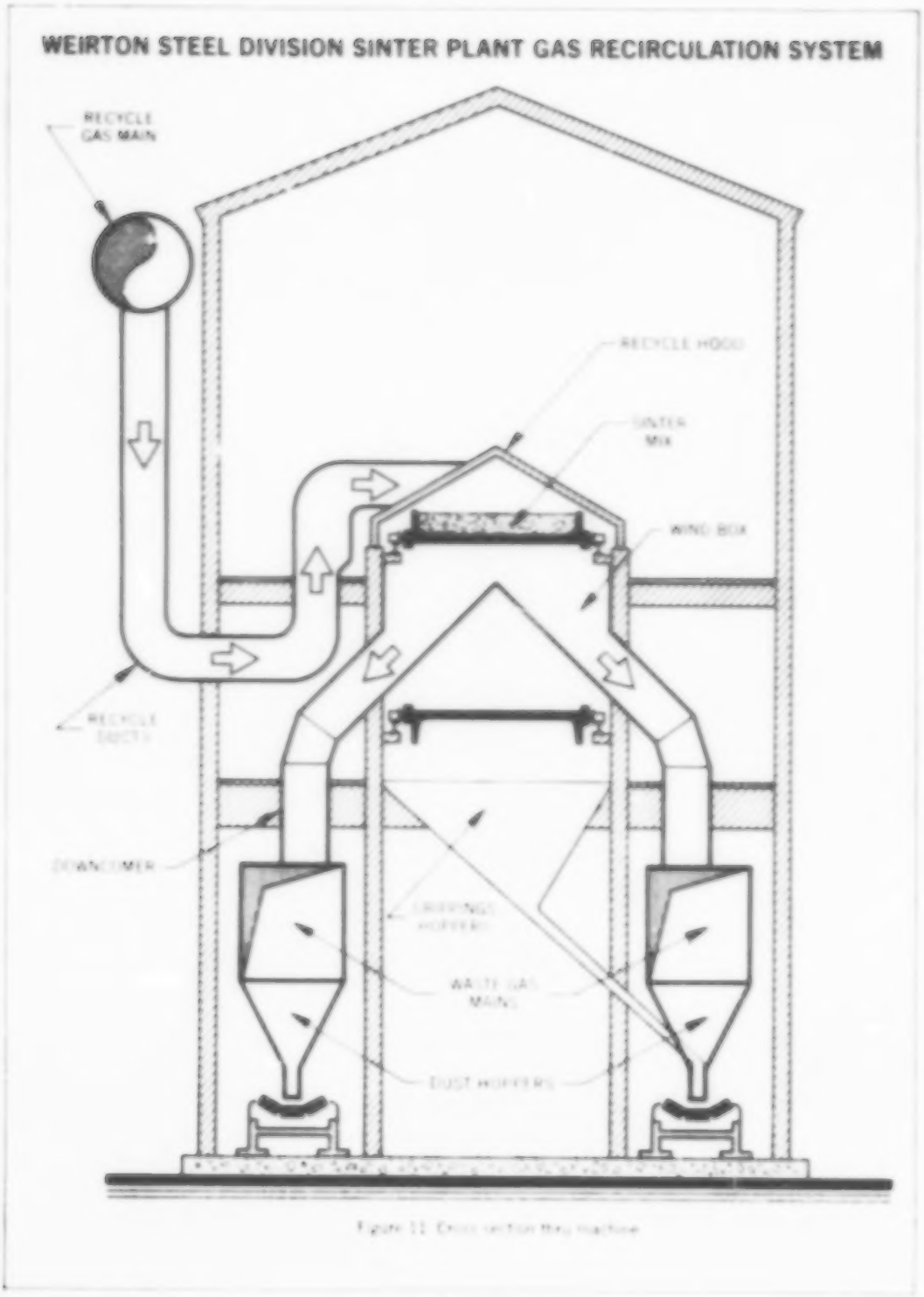

Figure 11. Cross section thru machine

ENVIRONMENTAL POSITION

The design concept introduced with this system was developed to reduce the air pollution conditions inherent in the handling of sinter machine waste gases. This system is intended as an interim step, to be followed later by the addition of a gas cleaning system to reduce the waste gas emissions in compliance with all applicable state and federal environmental codes. Several gas cleaning systems are under study; these were discussed briefly earlier in this section.

The conventional system, currently in use throughout the industry and presently in use at Weirton, discharges all sinter machine waste gases to atmosphere through a stack. Particulate discharge is reduced by passing the gases through multicloned or cyclone dust collectors.

The new system reduces the waste gases discharged to the atmosphere. Particulate emissions and hydrocarbon emissions are correspondingly reduced. The anticipated reduction in emissions for the number 2 sinter strand at Weirton with waste gas recirculation is thirty percent.

COST ESTIMATES

Capital Cost Estimate

The estimated capital cost of the gas recirculation system including engineering, equipment and installation is: $4,400,000

Operating Cost Estimate

Estimated annual operating costs for the gas recirculation system are as follows:

Power (additional for fans and controls, 2984 kw)	$315,000
Maintenance labor	$140,000
Maintenance material and spare parts	$ 50,000
Total annual cost	$505,000

SECTION VII

PRELIMINARY TEST PROGRAM DESIGN

INTRODUCTION

The following preliminary test program is intended to serve as a guide in preparing the work plan and scope of work for any future EPA contract executed to demonstrate the effectiveness of a windbox gas recirculation system for the reduction of sinter machine emissions. The windbox gas recirculation system should reduce the energy required and volume of gas to be cleaned. The gas not recirculated must be cleaned in a separate facility before it is released to the atmosphere. The program should, therefore, include tests of the separate and combined facilities. Pursuant to this goal, the following four-step program is recommended.

STEP I - PROJECT PREPARATION

Step I should include preparation of a work plan, and the design and installation of sampling facilities for the recirculation system and the gas cleaning system. Six months should be allowed for Step I starting with the completion of the recirculation and gas cleaning equipment installation.

STEP II - DEBUGGING AND TESTING OF THE WINDBOX GAS RECIRCULATION SYSTEM

Step II should allocate three months for debugging and optimization of the windbox gas recirculation system. Upon selection of a satisfactory recirculation rate, emission characterization and system evaluation tests should be started. These tests, extending over a period of six months, should include:

Determination of sinter feed materials quantities.

Analysis of the sinter machine gas. These determinations must be made in conformance with EPA methods for particulate sampling as stated in the Federal Register, and should include:

Velocity traverses
Gas analyses
Particulate mass loadings
Moisture determinations

Each test should be repeated a minimum of three times at the selected recirculation rate. Tests should be repeated periodically during the six-month interval as required to establish that conditions are stable.

Velocity and temperature monitoring of the waste gas and recirculated gas to determine the recirculation rate at any desired time.

Sampling to determine sulfur dioxide concentrations in the effluent gases.

Sampling of condensable hydrocarbons to determine the reduction accomplished by windbox gas recirculation. Areas sampled should include:

Raw materials feed

Sinter product

Windbox

Recycle gas

STEP III - DEBUGGING AND TESTING OF THE FINAL AIR POLLUTION CONTROL DEVICE

In Step III, three months should be allotted for debugging and optimization of the final air pollution control device. After this period, a six-month test and evaluation of the air pollution control device should be undertaken. This testing should determine the device's efficiency for removing both particulate and condensable hydrocarbon emissions.

STEP IV DEBUGGING AND TESTING OF THE COMBINED FACILITY

Step IV follows after the previous steps have established that the waste gas recirculation and the air pollution control systems have merit as independent facilities. Step IV then evaluates the results of operating both systems simultaneously as if they were a unified pollution control facility.

Three months should be allotted to step IV testing to determine the effectiveness of particulate and condensable hydrocarbon removal in the combined facility.

At the conclusion of these steps a final report should be prepared to describe the program and document the results of the emissions tests.

SECTION VIII

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4. AISI Technical Committee on Blast Furnace Practice, Quarterly Sinter Plant Data, Second Quarter, 1962.

5. AISI Technical Committee on Blast Furnace Practice, Operating Data, First Quarter, 1973.

6. Suitlas, J. R., "Emission Characteristics and Pilot Plant Studies on a Sintering Plant Windbox Discharge," TMS-AIME Ironmaking Proceedings, Volume 30, 1971, Page. 461.

SECTION IX

BIBLIOGRAPHY

The following publications represent a comprehensive bibliography of the sintering process and associated topics. Included are publications relating to the fundamentals of the sintering process, factors influencing the sintering process and its control, chemical and physical properties of sinter, sinter mineralogy, sinter basicity and its relationship to the sintering process, sinter properties, and sinter plant emissions. The material is organized into four categories, in accordance with the basic theme of the publication:

Fundamentals of the Sintering Process
Sinter Chemistry, Mineralogy and Basicity
Sinter Plant Process Variables, Materials and Control
Sinter Plant Emissions

All articles are available in English. In addition, the following sources offer comprehensive information on the sintering process and/or extensive bibliographies:

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SECTION X

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APPENDIX A

FIELD TEST DATA FOR WEIRTON STEEL'S NO. 2 SINTER PLANT

GENERAL

The following sections contain field test data from the files of the Weirton Steel Division, National Steel Corporation Environmental Control Department. The field testing was conducted to determine the concentration and mass loading of emissions from the stack serving the Weirton Steel Division No. 2 Sinter Machine windbox system. In addition, the effluent gas from each individual windbox on the No. 2 Sinter Machine was analyzed to determine its composition. This data represents the most recent testing of the No. 2 Sinter Machine main windbox gas discharge system.

NO. 2 SINTER PLANT MAIN STACK TESTING

A sampling program was developed by Weirton Steel Division to characterize emissions from the main stack at the No. 2 Sinter Plant. This program was conducted during July, 1971. Sampling procedures used for the program differed from Environmental Protection Agency recommended methods, since the program preceded the adoption of these methods. However, techniques were utilized which conformed to accepted practices at the time; for example, particulate determinations were performed according to Power Test Code 27, which includes average point sampling. Table 15 summarizes the stack parameters. Tables 16 through 19 present the data taken during the test period.

Table 15. SUMMARY OF STACK TEST DATA

Parameter		Average
Gas flow	Nm^3/s	163.4
	(scfm)	(373,000)
Particulate	mg/m^3	496.5
	(grains/scf)	(0.217)
Moisture	(weight) %	3.52
Sulphur dioxide	mg/m^3	250.25
	(ppm)	(94)
Condensable hydrocarbons	mg/m^3	160.2
	(grains/scf)	(0.07)
Stack gas temperature	°C	132
	(°F)	(270)
Sinter machine charge rate	mtph	336
	(tph)	(370)
Total enthalpy	j/g	247
	(Btu/lb)	(106.4)

Table 16. PARTICULATE EMISSIONS DATA

Test No.	1971 Date	Water weight %	Particulate		Hydrocarbons		Sulfur Dioxide	
			mg/m^3 (a) (grains/scf)	kg/mt (lbs/ton)	mg/m^3 (grains/scf)	kg/mt (lbs/ton)	mg/m^3 (ppm) (b)	kg/mt (lbs/ton)
1	7-13	3.84	263.12 (0.115)	0.496 (0.99)	-	-	-	-
2	7-14	3.31	-	-	-	-	-	-
3	7-15	3.62	251.68 (0.110)	0.476 (0.95)	130.42 (0.057)	0.246 (0.492)	-	-
4	7-19	2.92	858.0 (0.375)	1.62 (3.24)	205.92 (0.090)	0.389 (0.778)	-	-
5	7-20	3.82	514.8 (0.225)	0.973 (1.946)	-	-	-	-
6	7-20	3.75	702.42 (0.307)	1.327 (2.654)	-	-	-	-
7	7-21	3.80	411.84 (0.180	0.878 (1.757)	-	-	332.78 (125)	0.692 (1.384)
8	7-22	3.59	393.54 (0.172)	0.743 (1.486)	-	-	223.63 (84)	0.465 (0.930)
9	7-22	3.36	576.58 (0.252)	1.089 (2.178)	-	-	193.34 (73)	0.405 (0.810)
10	7-28	3.27	-	-	141.86 (0.062)	0.269 (0.538)	-	-
11	7-28	3.5	-	-	162.45 (0.071)	0.304 (0.608)	-	-
Average		3.52	496.5 (0.217)	0.938 (1.876)	160.16 (0.070)	0.303 (0.605)	250.25 (94)	0.52 (1.04)

(a) mg/m^3 at standard conditions, 21°C (70°F) and 1.0 atmosphere pressure
(b) ppm by volume

Table 17. SINTER MIX COMPOSITION
Metric tons per hour (short tons per hour)

	%	FeO	Fe_2O_3	Fe_3O_4	$CaCO_3$	$MgCO_3$
Labrador ore	29.5		77.27 (85.20)	-	-	-
Hanna ore	25.85	-	57.32 (63.20)	-	-	-
Lauretta ore	1.47	-	2.60 (2.87)	-	-	-
Coke breeze	7.28	-	0.39 (0.43)	0.37 (0.41)	-	-
Flue dust	2.57	-	2.31 (2.55)	2.24 (2.47)	-	-
Roll scale	2.91	7.16 (7.90)	-	-	-	-
Filter cake	2.81	-	2.30 (2.54)	2.27 (2.50)	-	-
Spore stone	14.75	-	0.24 (0.26)	-	31.38 (34.6)	5.90 (6.50)
Correy stone	12.73	-	0.21 (0.23)	-	18.14 (20.0)	15.60 (17.20)
Total		7.16 (7.90)	142.64 (157.28)	4.88 (5.36)	49.52 (54.2)	21.50 (23.70)

Table 17. (continued)
Metric tons per hour (short tons per hour)

CaO	MgO	SiO_2	Al_2O_3	C	S	P	Mn
0.048 (0.053)	0.039 (0.043)	6.13 (6.76)	1.11 (1.22)	-	0.006 (0.007)	0.063 (0.069)	0.412 (0.454)
0.062 (0.068)	0.151 (0.166)	7.39 (8.15)	0.28 (0.31)	-	0.008 (0.009)	0.034 (0.038)	0.204 (0.225)
0.022 (0.024)	0.006 (0.007)	0.57 (0.63)	0.04 (0.04)	-	-	0.003 (0.003)	0.210 (0.232)
0.011 (0.012)	0.091 (0.100)	0.96 (1.06)	0.43 (0.47)	15.51 (17.10)	0.190 (0.210)	-	-
0.274 (0.302)	0.170 (0.187)	0.28 (0.31)	0.12 (0.13)	1.19 (1.31)	0.021 (0.023)	-	-
0.050 (0.055)	0.033 (0.036)	0.03 (0.03)	0.01 (0.01)	-	0.028 (0.031)	-	-
0.041 (0.045)	0.114 (0.126)	0.66 (0.73)	0.10 (0.11)	1.52 (1.68)	0.003 (0.003)	-	-
-	-	0.85 (0.94)	0.47 (0.52)	-	0.013 (0.014)	-	-
-	-	0.10 (0.11)	0.06 (0.07)	-	0.020 (0.022)	-	-
0.503 (0.555)	0.603 (0.665)	16.98 (18.72)	2.61 (2.88)	18.22 (20.09)	0.289 (0.319)	0.100 (0.110)	0.826 (0.911)

Table 18. WINDBOX GAS FLOW AND TEMPERATURE (EXISTING SYSTEM)

Windbox number	Static Pressure (Negative) mm wc (in wc)	Temp. °C (°F)	Wind m^3/s (acfm)	Pressure atmos. Pa mm wc (in wc)	Pressure water vap. Pwv mm wc (in wc)
1	566.4 (22.3)	74 (165)	9.39 (19984)	9555.5 (376.2)	548.6 (21.6)
2	716.3 (28.2)	76 (168)	11.53 (24531)	9405.6 (370.3)	538.5 (21.2)
W 3	622.3 (24.5)	81 (178)	5.29 (11256)	9499.6 (374.0)	546.1 (21.5)
E 4	607.1 (23.9)	77 (171)	11.34 (24132)	9514.8 (374.6)	546.1 (21.5)
S 5	635.0 (25.0)	76 (169)	10.25 (21804)	9486.9 (373.5)	543.6 (21.4)
T 6	-	-	-	-	-
7	617.2 (24.3)	84 (184)	7.51 (15981)	9504.7 (374.2)	546.1 (21.5)
S 8	645.2 (25.4)	103 (217)	4.13 (8796)	9476.7 (373.1)	543.6 (21.4)
I 9	640.1 (25.2)	103 (217)	15.50 (32984)	9481.8 (373.3)	543.6 (21.4)
D 10	594.4 (23.4)	136 (276)	8.33 (17728)	9527.5 (375.1)	548.6 (21.6)
E 11	635.0 (25.0)	161 (321)	15.08 (32084)	9486.9 (373.5)	543.6 (21.4)
12	604.5 (23.8)	246 (475)	18.54 (39443)	9517.4 (374.7)	546.1 (21.5)
13	472.4 (18.6)	295 (563)	17.46 (37153)	9649.5 (379.9)	553.7 (21.8)
14	502.9 (19.8)	274 (526)	26.75 (56912)	9619.0 (378.7)	553.7 (21.8)

Table 18. (continued)

Pa-Pwv mm wc (in wc)	Temp °K (°R)	Wind Nm^3/s (scfm)	Enthalpy dry gas E_{DG} kw (Btu/m x 10^3)	Enthalpy water vap. E_{WV} kw (Btu/□ x 10^3)
9006.8 (354.6)	347 (625)	6.47 (14700)	620.6 (35.3)	835.1 (47.5)
8867.1 (349.1)	349 (628)	7.81 (17750)	766.5 (43.6)	1010.9 (57.5)
8953.5 (352.5)	354 (638)	3.56 (8100)	376.2 (21.4)	462.4 (26.3)
8968.7 (353.1)	351 (631)	7.72 (17550)	777.0 (44.2)	1002.1 (57.0)
8943.3 (352.1)	349 (629)	7.02 (15950)	696.2 (39.6)	907.1 (51.6)
-	-	-	-	-
8958.6 (352.7)	358 (644)	5.02 (11400)	539.7 (30.7)	652.2 (37.1)
8933.2 (351.7)	376 (677)	2.62 (5950)	348.1 (19.8)	344.6 (19.6)
8938.3 (351.9)	376 (677)	9.79 (22250)	1306.2 (74.3)	1283.3 (73.0)
8978.9 (353.5)	409 (736)	4.88 (11100)	852.6 (48.5)	659.3 (37.5)
8943.3 (352.1)	434 (781)	8.27 (18800)	1742.2 (99.1)	1135.7 (64.6)
8971.3 (353.2)	519 (935)	8.54 (19400)	2746.0 (156.2)	1239.4 (70.5)
9095.7 (358.1)	568 (1023)	7.41 (16850)	2883.1 (164.0)	1116.3 (63.5)
9065.3 (356.9)	548 (986)	11.79 (26800)	4254.4 (242.0)	1715.8 (97.6)

Table 19. WINDBOX GAS FLOW AND TEMPERATURE (EXISTING SYSTEM)

Windbox number	Static Pressure (Negative) mm wc (in wc)	Temp °C (°F)	Wind m^3/s (acfm)	Pressure atmos Pa mm wc (in wc)	Pressure water vap. Pwv mm wc (in wc)
1	558.8 (22.0)	72 (161)	8.60 (18296)	9563.1 (376.5)	548.6 (21.6)
2	647.7 (25.5)	72 (161)	5.91 (12567)	9474.2 (373.0)	543.6 (21.4)
E 3	607.1 (23.9)	66 (150)	6.39 (13597)	9514.8 (374.6)	546.1 (21.5)
A 4	584.2 (23.0)	59 (138)	5.98 (12723)	9537.7 (375.5)	548.6 (21.6)
S 5	627.4 (24.7)	61 (141)	8.33 (17732)	9494.5 (373.8)	543.6 (21.4)
T 6	645.2 (25.4)	57 (134)	11.77 (25044)	9476.7 (373.1)	543.6 (21.4)
7	673.1 (26.5)	67 (152)	9.71 (20667)	9448.8 (372.0)	541.0 (21.3)
S 8	650.2 (25.6)	88 (191)	8.39 (17860)	9471.7 (372.9)	541.0 (21.3)
I 9	624.8 (24.6)	105 (221)	5.91 (12567)	9497.1 (373.9)	543.6 (21.4)
D 10	609.6 (24.0)	110 (230)	10.39 (22105)	9512.3 (374.5)	546.1 (21.5)
E 11	670.6 (26.4)	142 (287)	9.97 (21248)	9451.3 (372.1)	543.6 (21.4)
12	586.7 (23.1)	207 (404)	13.22 (28132)	9535.2 (375.4)	548.6 (21.6)
13	411.5 (16.2)	257 (495)	10.99 (23386)	9710.4 (382.3)	558.8 (22.0)
14	533.4 (21.0)	246 (475)	34.68 (73783)	9588.5 (377.5)	551.2 (21.7)

NO. 2 SINTER PLANT WINDBOX GAS TESTING

Air flow measurements and gas analysis of the individual windboxes of Weirton Steel Division No. 2 Sinter Machine were conducted January 24, January 29, and February 7, 1973. The following table presents the average windbox gas compositions.

Table 20. AVERAGE WINDBOX GAS COMPOSITION

Windbox Number	% O_2	% CO_2	% CO
1	16.6	3.2	0.27
2-10	13.4	9.6	1.26
11	16.1	5.6	0.80
12	17.3	4.8	0.33
13	17.9	2.8	0.09
14	19.2	1.6	0.09
Averages	15.4	6.7	0.82

Table 19. (continued)

Pa-Pwv mm wc (in wc)	Temp °K (°R)	Wind Nm^3/s (scfm)	Enthalpy dry gas E_{DG} kw (Btu/m x 10^3)	Enthalpy water vap. E_{WV} kw (Btu/m x 10^3)
9014.5 (354.9)	345 (621)	5.96 (13550)	559.0 (31.8)	770.0 (43.8)
8930.6 (351.6)	345 (621)	4.07 (9250)	379.7 (21.6)	525.6 (29.9)
8968.7 (353.1)	339 (610)	4.49 (10200)	383.2 (21.8)	525.6 (29.9)
8989.1 (353.9)	332 (598)	4.29 (9750)	327.0 (18.6)	550.3 (31.3)
8950.9 (352.4)	334 (601)	5.96 (13550)	460.6 (26.2)	766.5 (43.6)
8933.2 (351.7)	330 (594)	8.51 (19350)	625.8 (35.6)	1084.7 (61.7)
8907.8 (350.7)	340 (612)	6.78 (15400)	588.9 (33.5)	872.0 (49.6)
8930.6 (351.6)	362 (651)	5.52 (12550)	634.6 (36.1)	722.5 (41.1)
8953.5 (352.5)	378 (681)	3.74 (8500)	506.3 (28.8)	495.8 (28.2)
8966.2 (353.0)	383 (690)	6.47 (14700)	914.2 (52.0)	857.9 (48.8)
8907.8 (350.7)	415 (747)	5.72 (13000)	1068.9 (60.8)	773.5 (44.0)
8986.5 (353.8)	480 (864)	6.56 (14900)	1775.6 (101.0)	1107.5 (63.0)
9151.6 (360.3)	530 (955)	5.04 (11450)	1714.1 (97.5)	738.4 (42.0)
9037.3 (355.8)	519 (935)	16.02 (36400)	5150.9 (293.0)	2338.1 (133.0)

APPENDIX B

PROCESS DESIGN CALCULATIONS

INTRODUCTION

The continuity, energy, and momentum equations in this section were developed for an analysis of the waste gas recirculation system. The equations are developed for equilibrium conditions utilizing equations of state, heat transfer equations, and combustion and chemical data. After the equations were developed, system parameters were determined for selected recirculation rates. Computations using these equations established the 39% recirculation rate as optimum and provided the basis for the design and selection of the waste gas recycle system equipment. Values obtained from the computations are summarized in Table 14, page 62.

DESIGN BASIS (Existing System - 0% Recirculation)

Machine Size

Width	3.7 m (12')
14 Windboxes, each	3.7 m (12'-0") x 3.2 m (10'-6")
Bed area	163.5 m^2 (1760 ft^2)
Bed thickness	355.6 mm (14 in)
Pressure drop across bed and windboxes	762 mm (30 in)
Ignition furnace	
Fuel	Coke oven gas
Length	1.5 windboxes

Rated Production

Sinter product	263 metric tph (290 short tph)
Basicity ratio	2.0

Normal Feed Rate

Feed including hearth layer and hot fines	336 metric tph (370 short tph)

Sinter Cooler Feed

Hot sinter to cooler	268 metric tph (295 short tph)

Waste Gas Data

The following data is extracted or derived from the tables in Appendix A and other test data from the No. 2 Sinter Machine.

Total dry air	180.02 Nm^3/s (409,150 scfm) 233.1 kg/s (511.4 lbs/sec)
Total moisture	Based on 3.52% moisture from Table 15 of Appendix A 8.85 kg/s (19.5 lbs/sec)
Enthalpy	E_{DG} = 32997.6 kw (1.877×10^6 Btu/min) = 141.56 j/g (61.16 Btu/lb)

E_{WV} = 24492.4 kw
(1.393 × 10^6 Btu/min)

= 2767.50 j/g
(1191.8 Btu/lb)

System Pressure Drop

Once Through System - 0% recirculation

	mm wc	inches wc
Pressure drop across sinter bed	762	(30)
Pressure drop across cyclones	203	(8)
Pressure drop across ductwork	102	(4)
Pressure drop from fan through stack	51	(2)
Total system pressure drop (Fan static pressure rise)	1118	(44)

Fan Inlet Conditions

Pressure	-1067 mm wc	(-42 inches wc)
Gas Temperature	139°C	(282°F)
Gas Volume - Each Fan	160 m^3/s	(240,000 acfm)
Gas Density	0.801 kg/Nm^3	(0.0464 lb/scf)

CALCULATIONS

Each parameter listed in Table 14, page 62, is shown here, in the order used in the table, with an explanation of its origin or derivation.

1.0 Gas Flow Each Fan (Dry)

As previously defined in the Discussion, page 64, the total process wind volume is 176.0 Nm^3/s (400,000 scfm). The gas flow through each fan is 88 Nm^3/s (200,000 scfm).

2.0 Waste Gas Temperature at Fan

2.1 Equilibrium Moisture Content of Gas - Atmospheric air at 21°C (70°F), 50% relative humidity contains X = 9.48 g/Nm^3 (4.0 grains/scf) of moisture.

Waste gas with 0% recirculation contains Y = 49.2 g/Nm^3 (20 grains/scf) of moisture.

When recirculating waste gas, moisture content increases. The general equation for moisture content as a function of recycle ratio is derived as follows:

with M_1 = Moisture content above bed
M_2 = Moisture content below bed
R = % recirculation

First pass -

Above Bed: $M_1 = \frac{100-R}{100}X + \frac{R}{100}Y$

Below Bed: $M_2 = \frac{100-R}{100}X + \frac{R}{100}Y + Y - X$

Second pass -

$$M_1 = \frac{100-R}{100}X + \frac{R}{100}\left(\frac{100-R}{100}X + \frac{R}{100}Y + Y - X\right)$$

$$= \left(\frac{100-R}{100}X + \frac{R}{100}Y\right)\left(1 + \frac{R}{100}\right) - \frac{R}{100}X$$

$$M_2 = \left(\frac{100-R}{100}X + \frac{R}{100}Y\right)\left(1 + \frac{R}{100}\right) - \frac{R}{100}X + Y - X$$

Third pass -

$$M_1 = \frac{100-R}{100}X + \frac{R}{100}\left[\left(\frac{100-R}{100}X + \frac{R}{100}Y\right)\left(1 + \frac{R}{100}\right)\right.$$

$$\left. - \frac{R}{100}X + Y - X\right]$$

$$= \left(\frac{100-R}{100}X + \frac{R}{100}Y\right)\left[1 + \frac{R}{100} + \left(\frac{R}{100}\right)^2\right] - \frac{R}{100}X \cdot$$

$$\left(1 + \frac{R}{100}\right) + Y - X$$

$$M_2 = \left(\frac{100-R}{100}X + \frac{R}{100}Y\right)\left[1 + \frac{R}{100} + \left(\frac{R}{100}\right)^2\right] - \frac{R}{100}X$$

$$\left(1 + \frac{R}{100}\right) + Y - X$$

nth pass -

$$M_1 = \left(\frac{100-R}{100}X + \frac{R}{100}Y\right)\left[1 + \frac{R}{100} + \left(\frac{R}{100}\right)^2\right.$$

$$\left. + \left(\frac{R}{100}\right)^3 + \ldots + \left(\frac{R}{100}\right)^{n-1}\right] - \frac{R}{100}X$$

$$\left[1 + \frac{R}{100} + \left(\frac{R}{100}\right)^2 + \ldots + \left(\frac{R}{100}\right)^{n-1}\right]$$

$$M_2 = M_1 + Y - X$$

Since $-1 < \frac{R}{100} < 1$ then $\left(\frac{R}{100}\right)^{n-1}$ will approach zero as n increases and the sum of n-1 terms will approach $\frac{1}{1 - \frac{R}{100}}$

$= \frac{100}{100-R}$ as a limit.

$$M_1 = \left(\frac{100-R}{100}X + \frac{R}{100}Y\right)\frac{100}{100-R} - \frac{R}{100}\left(\frac{100}{100-R}\right)X$$

$$= \left(\frac{100-2R}{100}X + \frac{R}{100}Y\right)\frac{100}{100-R}$$

$$M_2 = \left(\frac{100-2R}{100}X + \frac{R}{100}Y\right)\frac{100}{100-R} + Y - X$$

= Moisture content in waste gas main

Moisture content at 39% recirculation - Inserting 39% recirculation into the above equations gives the following:

Above Bed: $M_1 = 1.64(0.22X + 0.39Y)$

Below Bed: $M_2 = M_1 + Y - X$

Inserting the values for X and Y gives:

$M_1 = 35.06$ g/Nm^3 (14.25 grains/scf)

$M_2 = 74.42$ g/Nm^3 (30.25 grains/scf)

Moisture content at R% recirculation - The waste gas moisture content for other recirculation rates similarly calculated are shown in the table below.

Table 21. MOISTURE CONTENT IN WASTE GAS MAIN

R % of waste gas recycled	M_2 Waste gas moisture content g/Nm^3 (gr/scf)
0	49.2 (20.0)
10	53.6 (21.8)
20	59.0 (24.0)
30	66.1 (26.9)
39	74.42 (30.25)
50	88.6 (36.0)

2.2 Enthalpy Rise Across the Recycle Fan -

$$H_R = \frac{kw}{kg/s} \qquad \left[\frac{42.4 \times bhp}{lbs/min}\right]$$

$$= \frac{3228}{93.72\ Nm^3/s \times 1.295\ kg/Nm^3} \qquad \left[\frac{42.4 \times 4327 \times 13.3}{213{,}000\ scfm\ cf/lb}\right]$$

$$= 26.6\ j/g \qquad (11.46\ Btu/lb)$$

Where recycle fan kilowatts when handling 93.72 Nm^3/s (213,000 scfm) of waste gas = 3228 (4327 bhp) as stated by Green Fuel Co., manufacturers of the recycle fan.

2.3 Recycle Gas Ductwork Heat Loss -

Assumptions - The assumptions used in calculating the duct heat loss are:

Exterior of ductwork is insulated with rigid fiberglass 2 inches thick. Ductwork interior is bare steel without insulation.

Waste gas enters recycle fan at 194°C (382°F).

Building and exterior temperature 20°C (70°F), still air.

Recycled waste gas thermodynamically similar to air.

Heat loss calculations - The general equation used is:

$$Q = A \times U \times \Delta T$$

where Q = Heat loss, kw (Btu/hr)

U = Heat transfer coeff., kw/m^2°K (Btu/hr ft^2°F)

ΔT = Waste gas temp. - ambient temp. °K (°F)

A = Surface area, m^2 (ft^2)

Table 22. DUCTWORK HEAT LOSS

Location	Surface area m^2 (ft^2)	Heat loss Q, kw (Btu/h)	Heat Trans. Coef.	Temp. Diff. °K (°F)
1. Insulated ductwork	1,468 (15,800)	275 (940,000)	0.0011 (0.19)	173 (312)
2. Cyclones (Lined, uninsulated)	260 (2,800)	322 (1,100,000)	0.0071 (1.25)	175 (315)
3. Waste Gas mains (bare steel)	1,412 (15,200)	5,391 (18,400,000)	0.0207 (3.65)	184 (332)
4. Downcomers & Hoppers (bare steel)	1,412 (15,200)	5,860 (20,000,000)	0.0215 (3.8)	193 (347)
5. Insulated recycle ducts from fan to machine hood	1,612 (17,350)	346 (1,180,000)	0.0011 (.19)	219 (395)
6. Uninsulated machine hood	139 (1,500)	176 (600,000)	0.0150 (2.65)	83 (150)

Total recirculated gas heat loss (Q_R):

$$Q_R = 0.39(Q_1 + Q_3 + Q_4) + Q_5 + Q_6$$

= 5143 kw (17,500,000 Btu/h)

Enthalpy loss (H_D):

$$H_D = \frac{5143}{73.04 \times 1.295}$$

$$= 54.37 \text{ j/g} \quad (23.4 \text{ Btu/lb})$$

2.4 Recirculated Gas Temperature Equilibrium - The enthalpy of outside air at 21°C (70°F) and 50% relative humidity is:

$$H_A = E_{DG} + \frac{M}{D} \times E_{WV} \qquad \left(\text{j/g} + \frac{\text{g/Nm}^3}{\text{g/Nm}^3}\ \text{j/g}\right)$$

$$= 21.219 + \frac{9.48}{1295} \times 2537.55$$

$$= 39.8 \text{ j/g} \quad (17.4 \text{ Btu/lb})$$

The enthalpy of waste gas at the fan inlet when operating with 0% recirculation, 139°C (282°F) and 49.2 g/Nm^3 (20 grains/scf) of moisture is:

$$H_B = E_{DG} + \frac{M}{D} \times E_{WV}$$

$$= 141.56 + \frac{49.2}{1295} \times 2767.5$$

$$= 246.7 \text{ j/g} \quad (106.1 \text{ Btu/lb})$$

The enthalpy gain less ductwork loss is:

$$H_C = H_R - H_D$$

$$= 26.6 - 54.37$$

$$= -27.77 \text{ j/g} \quad (-11.9 \text{ Btu/lb})$$

When recirculating waste gas, the gas temperature increases. The general equation for thermal equilibrium as a function of recycle ratio is derived as follows:

with H_1 = Gas enthalpy above bed
H_2 = Gas enthalpy below bed
R = % recirculation

First pass -

Above bed: $H_1 = \frac{100-R}{100} H_A + \frac{R}{100} (H_B + H_C)$

Below bed: $H_2 = \frac{100-R}{100} H_A + \frac{R}{100} (H_B + H_C) + H_C + H_B - H_A$

Second pass -

$$H_1 = \frac{100-R}{100} H_A + \frac{R}{100} \left[\frac{100-R}{100} H_A + \frac{R}{100} (H_B + H_C) + H_C + H_B - H_A\right]$$

$$= \left[\frac{100-R}{100} H_A + \frac{R}{100} (H_B + H_C)\right] \left(1 + \frac{R}{100}\right) - \frac{R}{100} H_A$$

$$H_2 = \left[\frac{100-R}{100} H_A + \frac{R}{100} (H_B + H_C)\right] \left(1 + \frac{R}{100}\right) - \frac{R}{100} H_A + H_B - H_A$$

nth pass -

$$H_1 = \left[\frac{100-R}{100} H_A + \frac{R}{100} (H_B + H_C)\right] \left[1 + \frac{R}{100} + \left(\frac{R}{100}\right)^2 + \ldots \left(\frac{R}{100}\right)^{n-1}\right] - \frac{R}{100} H_A \left[1 + \frac{R}{100} + \left(\frac{R}{100}\right)^2 + \ldots \left(\frac{R}{100}\right)^{n-2}\right]$$

$$H_2 = [\frac{100-R}{100}H_A + \frac{R}{100}(H_B + H_C)] [1 + \frac{R}{100} + (\frac{R}{100})^2 + \ldots$$

$$(\frac{R}{100})^{n-1}] - \frac{R}{100}H_A [1 + \frac{R}{100} + (\frac{R}{100})^2 + \ldots$$

$$(\frac{R}{100})^{n-2}] + H_B + H_A$$

Since $-1 < \frac{R}{100} < 1$ then $(\frac{R}{100})^{n-1}$ will approach zero as n increases and the sum of n-1 terms will approach

$$\frac{1}{1 - \frac{R}{100}} = \frac{100}{100-R}$$

$$H_2 = [\frac{100-R}{100}H_A + \frac{R}{100}(H_B + H_C)] \frac{100}{100-R} - \frac{R}{100}H_A (\frac{100}{100-R}) + H_B - H_A$$

$$= [\frac{100-2R}{100}H_A + \frac{R}{100}(H_B + H_C)] \frac{100}{100-R} + H_B - H_A$$

= Gas Enthalpy in Waste Gas Main

The gas temperature is interpolated from the enthalpy calculated and enthalpy tables for air.

With the temperature established, a check calculation on the enthalpy is made using the table values for enthalpy at temperature.

The general equation is:

$$E = E_{DG} + \frac{M}{D} \times E_{WV} \quad j/g \text{ (Btu/lb)}$$

The general equations for thermal equilibrium with 39% recirculation become:

Gas enthalpy above bed $H_1 = 0.36A + 0.64 (H_B + H_C)$

Gas enthalpy below bed $H_2 = E_1 + H_B - H_A$

Inserting the values for H_A, H_B and H_C gives

$H_1 = 156.13$ j/g (67.2 Btu/lb)
$H_2 = 361.45$ j/g (155.6 Btu/lb)

The temperature of the gas above the bed (using H_1 and tables for air) is:

$T_1 = 84°C$ (183°F)

From tables (check calculation)

$$H_1 = E_{DG1} + \frac{M}{D} \times E_{WV1}$$

$$= 84.45 + \frac{35.06}{1295} \times 2647.72 = 156.13 \text{ j/g (67.2 Btu/lb)}$$

The temperature of the gas entering the fans (using H_2 and tables for air) is:

$T_2 = 194°C$ (382°F)

From tables (check calculation)

$$H_2 = E_{DG2} + \frac{M}{D} \times E_{WV2}$$

$$= 196.88 + \frac{74.42}{1295} \times 2862.03 = 361.45 \text{ j/g (155.6 Btu/lb)}$$

3.0 Pressure Drop Across 355.6 mm (14 in) Sinter Bed

At 39% recirculation, the pressure drop across the sinter bed due to temperature change, using Sutherland's formula for viscosity is:

$$\Delta P = \Delta P_o \left(\frac{T}{T_o}\right)^{1.5} \left(\frac{T_o + 120}{T + 120}\right) \text{ mm wc} \quad \text{(in wc)}$$

where $T_o = \frac{21 + 139}{2} + 273 = 353°K$ (636°R) (Zero Recycle)

$T = \frac{84 + 194}{2} + 273 = 412.5°K$ (742.5°R) (39% Recycle)

$\Delta P_o = 762$ mm wc (30 in)

$$P = 762 \left(\frac{412.5}{353}\right)^{1.5} \left(\frac{353 + 120}{412.5 + 120}\right)$$

$= 856$ mm wc (33.7 in)

4.0 Pressure Drop Existing Cyclones

For 39% recirculation, the pressure drop across the cyclones, using temperature correction,

$= 203 \times \frac{467}{412} = 230$ mm wc (9 in)

5.0 Pressure Drop Ductwork to Fan

For 39% recirculation, the pressure drop across the existing ductwork, using temperature correction,

$= 102 \times \frac{467}{412} = 116$ mm wc (4.5 in)

The pressure drop across new ductwork

= 20 mm wc (0.8 in)

The total pressure drop across the ductwork to the fan

= 136 mm wc (5.3 in)

6.0 Fan Inlet Negative Pressure

At 39% recirculation, the sum of the pressure drop is -1220 mm wc (-48 in) at 194°C (382°F)

7.0 Gas Volume at Fan Inlet

At 39% recirculation the gas flow including moisture

= 93.72 Nm^3/s (213,000 scfm)

Correcting this for gas density gives

184.7 m^3/s (393,000 acfm)

8.0 Gas Density

At 39% recirculation, the density corrected to inlet conditions gives 0.646 kg/m^3 (0.0403 lbs/cf)

9.0 Pressure Drop Fan to Hood

At 39% recirculation, the pressure drop in the duct from the fans to the hood = 70 mm wc (2.8 in)

10.0 Fan Static Pressure

At 39% recirculation, the sum of fan inlet pressure and drop to hood = 1290 mm wc (50.8 in)

Two fans, each with a capacity of 184.71 m^3/s (393,000 acfm) at 0.646 kg/m^3 (0.0403 lb/cf) density are required.

11.0 Fan Power

At 39% recirculation, the fan power determined by the fan manufacturer is 3228 kw (4327 bhp).

12.0 Volume Recycled (Dry)

Recirculation of 39% of the total dry gas flow of 176 Nm^3/s (400,000 scfm) = 68.6 Nm^3/s (156,000 scfm).

13.0 Volume Recycled to Hood

The standard volume of 68.6 Nm^3/s (156,000 scfm) recycled, corrected for density = 136.88 m^3/s (290,000 acfm).

14.0 Waste Gas Composition

14.1 Operating Conditions - The waste gas analysis is based on a sinter production rate of 263 mtph (290 net stph) with a basicity ratio of 2.0 and a sinter mix composition as shown in Appendix A, Table 17.

14.2 Oxygen Loss to Sinter Bed - The oxygen used in the oxidation of metallics and the combustion of fuel in the sinter feed is determined as follows:

FeO to Fe_2O_3 ($4FeO + O_2$ to $2Fe_2O_3$)

$$= \frac{7.16 \times 1000 \times 1000 \times 22.4}{3600 \times 32 \times 1000} \times \frac{32}{4 \times 71.85}$$

$$= 0.1550 \text{ Nm}^3/\text{s} \qquad (353.7 \text{ scfm})$$

Fe_3O_4 to Fe_2O_3 ($4Fe_3O_4 + O_2$ to $6Fe_2O_3$)

$$= \frac{4.88 \times 1000 \times 1000 \times 22.4}{3600 \times 32 \times 1000} \times \frac{32}{4 \times 231.55}$$

$$= 0.0328 \text{ Nm}^3/\text{s} \qquad (74.7 \text{ scfm})$$

C to CO_2 ($C + O_2$ to CO_2)

$$= \frac{18.22 \times 1000 \times 1000 \times 22.4}{3600 \times 32 \times 1000} \times \frac{32}{12}$$

$$= 9.4474 \text{ Nm}^3/\text{s} \qquad (21540.9 \text{ scfm})$$

MnO to Mn_3O_4 ($6MnO + O_2$ to $2Mn_3O_4$)

$$= \frac{0.826 \times 1000 \times 1000 \times 22.4}{3600 \times 32 \times 1000} \times \frac{32}{6 \times 54.94}$$

$= 0.0156\ Nm^3/s$ (35.6 scfm)

FeS_2 to $Fe_2O_3 + SO_2$ ($4FeS_2 + 11\ O_2$ to $2Fe_2O_3 + 8SO_2$)

$$= \frac{0.289 \times 1000 \times 1000 \times 22.4}{3600 \times 32 \times 1000} \times \frac{11 \times 32}{8 \times 32}$$

$= 0.0773\ Nm^3/s$ (176.4 scfm)

14.3 Total Oxygen Loss - The summation of the above oxygen losses gives
$L = 9.728\ Nm^3/s$ (22,181 scfm)

By test, the waste gas analysis should average oxygen content of 15.4%. See Appendix A, Table 20. From this the oxygen loss in the sinter bed was determined to be

$L = 180.02\ (0.21 - 0.154) = 10.03\ Nm^3/s$ (22,800 scfm)

This latter value is accepted as correct and is used in the subsequent calculations.

14.4 Oxygen Equilibrium as a Function of Gas Recycle Ratio - When recirculating waste gas, the oxygen content decreases. For a single pass system, i.e., R = 0, the oxygen content below the bed

$O_2 = 0.21\ W - L\ Nm^3/s$ (scfm), where

L = oxygen loss = $10.03\ Nm^3/s$ (22,800 scfm)
W = waste gas flow = $187.44\ Nm^3/s$ (426,000 scfm)
R = % recirculation

For R% recirculation, the general equation for oxygen content below the bed is derived as follows:

First pass -

$$O_2 = \frac{R}{100}(0.21W - L) + \frac{100-R}{100}(0.21W) - L$$

$$= \frac{R}{100}(0.21W) - L\left(1 + \frac{R}{100}\right) + \frac{100-R}{100}(0.21W)$$

Second pass -

$$O_2 = \frac{R}{100}\left[\frac{R}{100}(0.21W) - L\left(1 + \frac{R}{100}\right) + \frac{100-R}{100}(0.21W)\right]$$

$$+ \frac{100-R}{100}(0.21W) - L$$

$$= \left(\frac{R}{100}\right)^2(0.21W) - L\left[1 + \frac{R}{100} + \left(\frac{R}{100}\right)^2\right] + \frac{100-R}{100}\left(1 + \frac{R}{100}\right)$$

$$(0.21W)$$

nth pass -

$$O_2 = \left(\frac{R}{100}\right)^n(0.21W) - L\left[1 + \frac{R}{100} + \left(\frac{R}{100}\right)^2 + \ldots + \left(\frac{R}{100}\right)^{n-1}\right]$$

$$+ \frac{100-R}{100}(0.21W)\left[1 + \frac{R}{100} + \ldots \left(\frac{R}{100}\right)^{n-2}\right]$$

Since $-1 \quad \frac{R}{100} \quad 1$ then $\left(\frac{R}{100}\right)^{n-1}$ will approach zero as n increases and the sum of n-1 terms will approach $\frac{1}{1 - \frac{R}{100}} = \frac{100}{100-R}$

$$O_2 = -L\frac{100}{100-R} + \frac{100-R}{100}(0.21W)\frac{100}{100-R}$$

$$= 0.21W - \frac{100}{100-R}L$$

% O_2 Below Bed

$$= \frac{100}{W} \left(0.21W - \frac{100}{100-R} L\right)$$

$$= 21 - \frac{100}{100-R} \left(\frac{100L}{W}\right)$$

% O_2 Above Bed

$$= \frac{R}{100} \left[21 - \frac{100}{100-R} \left(\frac{100L}{W}\right)\right] + \frac{100-R}{100} (21)$$

14.5 39% Recirculation - Inserting the values for L, W and R for 39% recirculation gives

Oxygen Above Bed: O_2 = 17.56%

Oxygen Below Bed: O_2 = 12.2%

14.6 Check on Gas Composition Using 39% Recirculation

Carbon dioxide - The average CO_2 in the waste gas at 0% recirculaton is 6.7%. (Ref. Table 20, page 108.)

Using this, CO_2 = W(0.067) (1.64) gives CO_2 = (6.7) (1.64) = 10.9% below the bed.

In the recycle hood, at 39% recirculation, CO_2 = (0.39) (10.9) = 4.25%

Carbon monoxide - The average CO in the waste gas main at 0% recirculation = .82%. (Ref. Table 20, page 108.)

This gives CO = (0.82) (1.64) = 1.34% below the bed.

In the recycle hood at 39% recirculation CO = (0.39) (1.34) = 0.53%

Gas composition summary - A summary of the calculated and derived gas composition values follows in Table 23.

Table 23. GAS COMPOSITION

39% Recirculation

Gas	Above Bed %	Below Bed %
O_2	17.5	12.2
CO_2	4.2	10.9
CO	0.5	1.3
N_2	73.6	67.1
H_2O	4.2	8.5
TOTAL	100.0	100.0

14.7 Calculated Gas Density - The gas density above and below the bed is calculated from the gas composition data in Table 23.

Above bed -

ρO_2 = 0.045 x 32 x 0.175 = 0.252
ρCO_2 = 0.045 x 44 x 0.042 = 0.082
ρCO = 0.045 x 28 x 0.005 = 0.006
ρN_2 = 0.045 x 28 x 0.736 = 0.920
ρH_2O = 0.045 x 18 x 0.042 = 0.034
ρGas @ 21°C (70°F) and
760 mm HG (14.7 psia) = 1.294 kg/Nm^3 (0.075 lb/scf)

Below bed -

CO_2 = 0.04 x 32 x 0.132 = 0.170
CO_2 = 0.04 x 44 x 0.109 = 0.216
CO = 0.04 x 28 x 0.013 = 0.014
N_2 = 0.04 x 28 x 0.671 = 0.854
H_2O = 0.04 x 18 x 0.085 = 0.069
Gas @ 21°C (70°F) and
760 mm Hg (14.7 psia) = 1.31 kg/Sm^3 (0.076 lb/scf)

15.0 Gas Flow to Stack

Total gas flow = 176 Sm^3/s (600,000 scfm) dry.

61% of this corrected for density at discharge conditions, 0.646 kg/Nm^3 (0.0403 lbs/ft),

= 212.9 m^3/s (451,000 acfm)

16.0 Saturated Gas Flow to Stack & Saturated Gas Temperature

16.1 General -

Enthalpy of waste gas discharge = enthalpy at fan inlet + enthalpy rise across fan

Using tables for saturated gas, this value will give the saturated gas temperature.

The specific volume of the gas at the saturated temperature (from table) times the mass flow, at the percentage recirculation being considered, gives the saturated volume flow.

16.2 39% Recirculation -

$E = E_1 + E_2$

E_1 = Gas enthalpy at fan inlet (calculated previously)

E_2 = Gas enthalpy rise in fan (calculated previously)

$E = 361.45 + 26.6$

$= 388.05$ j/g (167.2 Btu/lb)

From table: T = 57°C (134°F)

From table: Specific volume = 1.123 m^3/kg (18.0 ft^3/lb)

Mass Flow = 106.9 Nm^3/s x 1.295 kg/Nm^3

= 138.4 kg/s (18,300 lb/min)

Saturated Volume = 138.4 x 1.123

= 155.4 m^3/s (330,000 acfm)

SUMMARY

The relationships developed in Appendix B were the process design basis for the sinter plant waste gas recirculation system at the Weirton Steel Division No. 2 Sinter Plant. The numerical values derived for selected recirculation rates are summarized in Table 14, page 62. From these data, the 39% recirculation rate was selected as the optimum design point.